

**ASSESSMENT OF THE IMPACT OF CLIMATE
CHANGE ON FOOD SUPPLY CHAIN AND
LIVELIHOODS OF SMALLHOLDER VEGETABLE
FARMERS IN RURAL KWAZULU NATAL PROVINCE,
SOUTH AFRICA.**

by

Merishca Naicker (214504745)

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Degree of**

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South Africa

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Student's Signature:  Date: 06/02/2025

Miss Merishca Naicker

As the candidate's main supervisor, I, Prof Mjabuliseni Ngidi, agree to the submission of this thesis for examination.

Supervisor's signature:  Date: 06/02/2025

Prof. Mjabuliseni Simon Ngidi

As the candidate's co-supervisor, I, Dr Denver Naidoo, agree to the submission of this thesis for examination.

Co-Supervisor's Signature: ...  Date: 06/02/2025

Dr Denver Naidoo

DECLARATION 2: PUBLICATIONS

The following publications form part of the research presented in this study.

Publication 1- Chapter 2

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Data collection, analysis and writing of original article: Miss Merishca Naicker

Reviewing of the article: Dr Denver Naidoo, Prof Mjabuliseni Simon Ngidi and Prof Rob Slotow.

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Reviewing of the article: Dr Denver Naidoo, Dr Simphiwe Innocentia Hlatshwayo and Prof Mjabuliseni Simon Ngidi.

Student's Signature:  Date: 06/02/2025

Miss Merishca Naicker

As the candidate's main supervisor, I, Prof Mjabuliseni Ngidi, agree to the submission of this thesis for examination.

Supervisor's signature: Date: 06/02/2025

Prof. Mjabuliseni Simon Ngidi

As the candidate's co-supervisor, I, Dr Denver Naidoo, agree to the submission of this thesis for examination.

Co-Supervisor's Signature: ...  Date: 06/02/2025

Dr Denver Naidoo

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DEDICATIONS

This work is dedicated to my parents, Prema and Micheal Naicker, whose unwavering support, love, and encouragement have shaped me throughout my life. I am deeply grateful for everything you have done for me, and words cannot fully convey the immense value you both possess in my heart. Your belief in me has been a constant source of inspiration.

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ABSTRACT

Smallholder vegetable farmers cultivate crops for family use and sales. In South Africa, these farmers are facing numerous challenges due to climate change, such as increased pests and diseases and reduced crop yields due to fluctuations in temperatures and the climate. These challenges significantly affect the income of these smallholder farmers and the food supply chain negatively; hence they need effective strategies to overcome the obstacles caused by climate change to their food supply chain and livelihoods. The study's main objective was to assess the impact of climate change on the food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal Province (KZN). Using a mixed-methods design, 200 farmers were randomly selected from a population of 2,530 across 11 districts, based on a (95%) confidence level and (5%) margin of error. Quantitative data were gathered through questionnaires, while qualitative insights came from 22 key informant interviews and 12 focus group discussions. Analysis involved SPSS, STATA, SUR, Box-Cox, and multivariate probit models, with thematic analysis using NVivo 12.

The first objective of this study explored the effect of climate change on the food supply chain in Africa, with a focus on South Africa. A systematic literature review of 143 peer-reviewed articles (1993–2023) revealed that climate change significantly disrupts food supply chains by reducing crop yields, lowering food quality, and limiting market availability, thereby increasing food insecurity, especially among smallholder farmers reliant on rain-fed agriculture. Thematic analysis highlighted key areas of impact, including production, food safety, distribution, and adaptation. Effective responses require the adoption of Climate-Smart Agriculture, improved access to finance and climate information, and the integration of agriculture, trade, and climate policies to build resilient and sustainable food systems in vulnerable regions.

This second objective aimed to map the food supply chain in KwaZulu-Natal by identifying key actors, analysing its structure, and assessing vulnerabilities, particularly for smallholder farmers. Using a mixed-methods approach with data from 200 farmers and stakeholders, the findings revealed widespread land underutilization, reliance on informal markets, poor infrastructure, and limited institutional support. Climate change has intensified challenges, increasing production costs, crop failures, and food insecurity. The sector is further strained by an aging farming population and the growing dominance of informal traders. The study concludes that improving the resilience and sustainability of the supply chain requires targeted government support, investment in infrastructure, and strategies promoting climate-smart practices and formal market inclusion.

The third objective evaluated how smallholder vegetable farmers' perceptions of climate change affect their income in KwaZulu-Natal. Using a survey of 200 farmers and econometric analyses (SUR and Box-Cox models), results showed that (69%) experienced crop failures and (84%) reported reduced yields due to climate variability. Positive factors influencing crop management included marital status, land ownership, and participation in food networks, while larger households and sole reliance on farming reduced adaptive capacity and income. The findings highlight that farmers' ability to adapt is influenced by both socio-economic and perceptual factors. The study recommends tailored climate education, climate-smart practices, and better access to financial and digital resources to improve resilience and income among vulnerable smallholder farmers.

The fourth objective explored smallholder vegetable farmers' perceptions of climate change and its association on food security and income in KwaZulu-Natal. Surveying 200 farmers with both quantitative and qualitative methods, results showed that the majority (93%) recognized climate change impacts like erratic rainfall and rising temperatures, which significantly affected their production and income. Despite awareness, limited access to climate information, poor infrastructure, and institutional gaps hindered adaptation. With 85% relying solely on vegetable farming, economic vulnerability remains high. The study recommends policies promoting climate-resilient crops, water harvesting, real-time climate data dissemination, and tailored training, especially for older farmers, to strengthen resilience and sustain livelihoods amid climate challenges.

The last and fifth objective examined the factors influencing the choice and extent of climate adaptation strategies among smallholder vegetable farmers in KwaZulu-Natal. Surveying 200 farmers, results showed most experienced climate variability and adopted carbon- and water-smart practices. Using Multivariate Probit and Count Data models, findings revealed that education level and land size positively affected adaptation adoption, while marital status, household size, income source, soil type, association membership, and supply chain involvement negatively influenced adaptation choices and capacity. The study recommends stronger government support for Climate Smart Agriculture (CSA) through training, credit access, and technologies like hot houses to improve farmers' resilience and enhance food security.

The study concluded that climate change significantly disrupts smallholder vegetable production and the food supply chain in KwaZulu Natal, negatively impacting food security and livelihoods. Farmers' awareness of climate impacts and adoption of adaptation strategies are influenced by socio-economic and structural factors such as education, land tenure, and

access to resources. However, barriers including limited infrastructure, financial constraints, and inadequate institutional support restrict effective adaptation. Therefore, while adaptation strategies offer potential to enhance resilience, interventions must be contextually tailored to address these specific challenges. The findings highlight the need for integrated approaches combining technical assistance, improved infrastructure, climate education, and inclusive policies to strengthen the adaptive capacity and sustainability of smallholder farmers in the region.

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ACRONYMS AND ABBREVIATIONS

ACFS	African Centre for Food Security
AIC	Akaike information criterion
BIC	Bayesian information criterion
COVID-19	Coronavirus
CSA	Climate-Smart Agriculture
CTAFS	Centre for Transformative and Agricultural Food Systems
DALRRD	Department of Agriculture, Land Reform and Rural Development
DARD	Department of Agriculture and Rural Development
DFID	Department for International Development
FAO	Food and Agriculture Organisation
FGDs	Focused group discussions
GDP	Gross Domestic Product
GLM	Generalized Linear Model
HFIAS	Household Food Insecurity Access Score
HSSREC	Human and Social Sciences Research Ethics Committee
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
JBI	Joanna Briggs Inventory
KZN	KwaZulu Natal
NGO	Non-Governmental Organization
OLS	Ordinary Least Squares
SFSCs	short food supply chains
SLF	Sustainable Livelihood Framework
SPSS	Statistical Software for Social Sciences
STATS SA	Statistics South Africa
SUR	Seemingly Unrelated Regression model
VCA	Value Chain Analysis

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Globally the level of hunger experienced is distressingly high and affects the livelihoods and development of households (Drysdale *et al.*, 2021). South Africa is seen as a food secure nation at a national level however at a household level food insecurity is prevalent (Food and Agriculture Organisation, 2023). South Africa saw a decrease in the number of food insecure households from (13.5 million households) to (6.8 million households) as per Statistics South Africa (2021). Food security is when people's physical and economic access to safe and nutritious food must meet their dietary needs and food preferences for an active and healthy life (FAO, 1996). Verma, (2020) reported that population and household size growth are the main causes of household food insecurity in households.

Most of KwaZulu Natal's farming sector comprises subsistence and small-scale farmers who sell their produce in formal and informal markets (Myeni *et al.*, 2019). Smallholder vegetable farmers in South Africa are an important part of the country's agricultural sector and contribute significantly to food production and food safety. These smallholder farmers contribute to employment, rural development, and the food security of the province (Mahlalela & Makhathini, 2021). The main types of crops grown by the smallholder farmers are maize, vegetables and potatoes (Ncube *et al.*, 2020). As presented by Ravhura & Shumba (2021) smallholder farmers face many challenges such as access to land, market access, limited finances and climate change. Although smallholder farmers face many challenges, they are still essential to the country's agricultural sector (Tshuma *et al.*, 2019; Mairura *et al.*, 2021). Vegetable crops play a crucial role in enhancing dietary diversity and addressing micronutrient deficiencies among rural households in KwaZulu-Natal, thereby contributing to improved nutritional security (Food and Agriculture Organisation, 2017). Economically, smallholder vegetable farming offers viable income-generating opportunities, strengthening household resilience and contributing to local livelihoods through increased market participation (Van Averbekke *et al.*, 2011).

Agricultural activities such as subsistence farming are the key to overcoming food insecurity (Wegenast & Beck, 2020). In KwaZulu Natal, the majority of the population resides in rural areas and therefore faces many challenges such as the lack of job opportunities, poverty, and absence of education (Sewell *et al.*, 2019).

The ongoing issue of Climate Change has negatively affected the farming sector and has caused changes in the planting seasons of crops (Agrawal & Suryanarayana, 2020, Aryal *et al.*, 2020). It has also brought challenges such as pests and diseases that cause additional costs to farmers and loss of crops (Wiebe *et al.*, 2019). Therefore, Climate change has negatively impacted the Farming sector in KwaZulu Natal. The farming sector has found ways and continues to find ways to mitigate the impacts on crop production. Climate change is a contributing factor to food insecurity in South Africa (Amelework *et al.*, 2021). It is important to raise awareness about the impacts of climate change and to support policies and initiatives that address this critical issue of climate change (Guo, 2023).

The food supply chain in South Africa is complex and involves multiple stakeholders, including farmers, processors, distributors, retailers, and consumers (Shah *et al.*, 2021). The effects of COVID-19 have caused added stress to the economy and the food supply chain of smallholder farmers (Paganini *et al.*, 2020). Despite the significant contribution of the food supply chain to the South African economy, some challenges need to be addressed. These include issues such as food insecurity, high levels of food waste, and unequal access to resources and opportunities for smallholder farmers (Ray *et al.*, 2019; Molotsi *et al.*, 2019).

The Department of Agriculture and Rural Development (DARD) provides farmers with agricultural inputs such as seeds and chemicals to overcome challenges faced by smallholder farmers (Abegunde *et al.*, 2019; Ncube *et al.*, 2020). The South African government has taken a proactive approach to mitigating the impacts of climate change on smallholder farms and crop production (Molotsi *et al.*, 2019; Le & Vu, 2022). However, more needs to be done to ensure that smallholder farmers have access to the resources and support they need to adapt to climate change impacts and enhance their resilience for the future.

1.2. Statement of Research Problem

Smallholder farms in the KwaZulu Natal Province of South Africa rely heavily on agriculture, particularly vegetable production, as a primary source of livelihood and food security (Tshuma *et al.*, 2019). However, climate change presents a growing threat to this sector, leading to declining agricultural productivity, increased crop losses, and reduced household income. The region has experienced significant climate-related stressors, including irregular rainfall patterns, prolonged droughts, temperature extremes, and the proliferation of pests and diseases (Yende, 2020; Ravhura & Shumba, 2021). These changes have directly impacted the quality and quantity of vegetables produced, contributing to supply chain disruptions, food price volatility, and decreased access to nutritious food (Noble, 2023).

Despite the impacts of climate change on smallholder vegetable farmers, there is limited knowledge of the specific nature and extent of these impacts and the adaptation strategies that farmers can adopt to mitigate these impacts (Amelework *et al.*, 2021). Recent data from KwaZulu Natal indicate substantial fluctuations in vegetable yields and market prices, particularly during periods of erratic weather (such as floods) and pest outbreaks, which have intensified smallholder farmers' vulnerability (Department of Agriculture, Forestry and Fisheries, 2022; Stats SA, 2023). While the literature acknowledges the impact of climate change on staple crops such as maize, there remains a lack of focused research on its effects on vegetable farming in the province (Abegunde *et al.*, 2019; Ncube *et al.*, 2020; Yende, 2020). This gap limits the development of targeted, evidence-based adaptation strategies for smallholder vegetable farmers.

Therefore, this study aims to conduct an in-depth assessment of the impact of climate change on the food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal. By identifying the specific challenges faced and evaluating potential adaptation strategies, the study seeks to inform policies that can enhance the resilience and food security of this vulnerable farming population

1.3. Rationale/ Significance of the study

The rationale for this research stems from the urgent need to address the growing impact of climate change on agriculture and food systems, particularly in vulnerable regions such as KwaZulu Natal Province, South Africa (Ncube *et al.*, 2020; Hlatshwayo *et al.*, 2023). While the broader consequences of climate change on agriculture are well documented, limited attention has been paid to its specific effects on smallholder vegetable farming within this province. Given the province's reliance on small-scale agricultural activities for income generation and food production, understanding these dynamics is essential.

Vegetable production, which plays a central role in household nutrition and income generation, is increasingly under threat due to shifting climatic conditions (Mahlalela & Makhathini, 2021). Fluctuating temperatures, erratic rainfall, and increased pest infestations are expected to exacerbate yield volatility, strain food supply chains, and compromise food availability and affordability. These issues are particularly acute in rural areas of KwaZulu Natal, where poverty levels are high and adaptive capacity is limited (Mazibuko & Letsoko, 2024; Anekwe *et al.*, 2024).

This study provides a focused assessment of how climate change is affecting smallholder vegetable farmers and the regional food supply chain. It also seeks to identify and evaluate

locally relevant adaptation strategies that can enhance resilience among these farmers. In doing so, the study aims to fill a critical knowledge gap in existing research and provide evidence-based insights that can support policymaking, targeted intervention programs, and long-term food security planning. Additionally, the findings will contribute to the broader academic discourse on climate change adaptation in agriculture across sub-Saharan Africa.

1.4. Aims and objectives

1.4.1. Main Research Objective

To assess the impact of climate change on the food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal Province.

1.4.2. Specific Objectives

- i. To explore the effect of climate change on the food supply chain in Africa, with a focus on South Africa.
- ii. To map the food supply chain in KwaZulu Natal by identifying key actors, analysing the structure and assessing vulnerabilities within these systems.
- iii. To evaluate the association of climate change perceptions on the income of smallholder vegetable farmers in KwaZulu Natal Province.
- iv. To explore the perceptions of climate change on food security by the smallholder farmers in KwaZulu Natal Province.
- v. To determine the factors affecting the choice and level of adaptation strategies among smallholder vegetable farmers in KwaZulu Natal Province.

1.5. Research question

1. What is the overall impact of climate change on the food supply chain and the livelihoods of smallholder vegetable farmers in rural KwaZulu Natal Province?
2. What are the key vulnerabilities and disruptions in the food supply chain for smallholder vegetable farmers in KwaZulu Natal caused by climate change?
3. What are the key components and linkages of the food supply chain for smallholder vegetable farmers in KwaZulu Natal Province?
4. How do smallholder vegetable farmers' perceptions of climate change influence their income levels in KwaZulu Natal?

5. What adaptation strategies are currently employed by smallholder farmers in the province, and what additional policy interventions are needed to enhance resilience and sustainability in the food system?

1.6. Definition of terms

Food Security: Food security exists when people always have physical and economic access to safe and nutritious food to meet their dietary needs and food preferences for active and healthy life (FAO, 1996, Food and Agriculture Organisation, 2023).

Relevance to the study: Central to evaluating the well-being of smallholder farmers and their communities in the face of climate-induced disruptions.

Climate Change: A long-term change in the average weather patterns that have come to define Earth's local, regional, and global climates. Climate change is caused by various factors, including human activities such as burning fossil fuels and deforestation, as well as natural processes like volcanic eruptions and solar radiation.

Relevance to the study: Serves as the primary stressor examined in the study, impacting food production, supply chains, and rural livelihoods.

Food Supply Chain: The series of processes involved in the production, processing, packaging, storage, transportation, and distribution of food products from the farm to the table.

Relevance to the study: The study explores how this chain is affected by climate change and identifies points of vulnerability and resilience.

Livelihoods: How people make a living and support themselves and their families, including their income, employment, assets, and resources.

Relevance to the study: A core outcome variable affected by both climate change and supply chain stability.

Smallholder Farmers: Farmers who cultivate small plots of land, usually less than five hectares, and rely mainly on family labour to produce food and generate income.

Relevance to the study: This group forms the focal population of the study due to their sensitivity to environmental and economic shocks.

Vegetable Farming: The cultivation of vegetables for consumption and commercial purposes, including the production of crops like tomatoes, peppers, cucumbers, and leafy greens.

Relevance to the study: A key agricultural activity in KwaZulu-Natal that links smallholder livelihoods with regional food security.

Adaptation Strategies: Measures taken to adjust to the effects of climate change, including changes in agricultural practices, land use, water management, and other activities that help to reduce the vulnerability of communities to climate change impacts.

Relevance to the study: Central to the study's goal of identifying ways to enhance resilience among smallholder farmers.

Rural Areas: Areas located outside of urban and suburban areas, are characterized by low population densities, limited access to basic infrastructure and services, and a strong dependence on natural resources and agriculture for livelihoods.

Relevance to the study: The study is situated in rural KwaZulu-Natal, making this context essential to understanding constraints and opportunities.

KwaZulu Natal Province: A province located in the southeastern region of South Africa, known for its diverse culture, natural beauty, and agricultural production, including the production of crops like vegetables, sugar cane, and timber (FAO and United Nations Environment Programme, 2023).

Relevance to the study: The study site, characterised by high climate vulnerability and dependence on smallholder agriculture.

1.7. Outline of the thesis

This study consists of eight chapters, which include this introductory study.

CHAPTER TWO presents a systematic literature review titled "*Exploring the Effect of Climate Change on Food Supply Chains in Africa: A Systematic Review with a Focus on South Africa.*" It reviews the broader literature on climate change impacts on food supply chains, with emphasis on smallholder farmers in Africa and South Africa.

CHAPTER THREE outlines the methodology, detailing the data collection processes and analytical techniques used in the study.

CHAPTERS FOUR through **SEVEN** contain the core empirical studies addressing the research objectives:

CHAPTER FOUR: *To map the food supply chain in KwaZulu Natal by identifying key actors, analyzing the structure and assessing vulnerabilities within these systems.* Maps the food supply chain in KwaZulu-Natal using both qualitative and quantitative approaches to identify key challenges faced by smallholder farmers.

CHAPTER FIVE: *Evaluating the association of climate change perceptions on the income of smallholder vegetable farmers, in KwaZulu Natal province, South Africa.* Investigates how farmers' perceptions of climate change affect their income, using the Seemingly Unrelated Regression and Box-Cox models.

CHAPTER SIX: *The perceptions of climate change on food security by the smallholder farmers, in KwaZulu Natal.* Explores how climate change is perceived to influence food security among smallholder farmers, employing the Household Food Insecurity Access Scale (HFAS), alongside survey and focus group data.

CHAPTER SEVEN: *Factors Affecting the Choice and Level of Adaptation Strategies Among Smallholder Farmers in KwaZulu Natal Province.* Examines the determinants of adaptation strategies and their intensity using the Multivariate Probit Model and Count Data Model.

CHAPTER EIGHT: *Conclusions and Recommendations.* Synthesizes the findings, discusses policy implications, and outlines recommendations for future research.

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CHAPTER 2

EXPLORING THE EFFECT OF CLIMATE CHANGE ON FOOD SUPPLY CHAINS IN AFRICA: A SYSTEMATIC REVIEW WITH A FOCUS ON SOUTH AFRICA.

*Merishca Naicker ¹, Denver Naidoo ¹, Rob Slotow² *Mjabuliseni Simon Ngidi ¹,

¹School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, Pietermaritzburg 3201, South Africa.

²School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, Pietermaritzburg 3201, South Africa

*Correspondence: ngidim@ukzn.ac.za

Abstract

The food supply chain is a complex system involving multiple stakeholders, from production to consumption, and is shaped by factors such as trade policies, logistics, and environmental change. Climate change poses a major threat to this system, particularly for smallholder farmers who depend on rain-fed agriculture, have limited market access, and lack technical resources, making them especially vulnerable. Addressing these challenges requires proactive adaptation and collaborative action across all levels to build resilient and sustainable food systems.

This study conducted a systematic literature review using Web of Science, Scopus, and Google Scholar to assess the impact of climate change on smallholder farmers' food supply chains in relation to livelihoods, food security, resilience, and adaptation strategies. A total of 20,889 articles published between 1993 and 2023 were initially identified using relevant keywords. Following title, abstract, and full-text screening, 143 peer-reviewed articles were included. Quality assessment was conducted using the Joanna Briggs Inventory (JBI), and PRISMA guidelines were followed to ensure rigour. NVivo 12 software facilitated thematic analysis of key topics, including production, food safety, distribution, and adaptation.

Findings indicate that climate change significantly disrupts agricultural processes, affecting crop yield, quality, and market availability, while increasing food prices and insecurity. Adaptation strategies, such as changes in farming and water practices, and mitigation efforts like reforestation and greenhouse gas reduction, are essential. These strategies vary by region and depend on climate conditions and land tenure.

In conclusion, climate change continues to undermine food systems, necessitating the promotion of Climate-Smart Agriculture, access to financial services and climate information, and integration of climate, agriculture, and trade policies. Targeted policies and collaborative efforts are vital for supporting smallholder farmers and ensuring resilient food supply chains in vulnerable regions like South Africa.

Keywords: Climate change; food supply chain; agricultural production; food security; adaptation

2.1. Background

Climate change signifies widespread alterations in temperature and atmospheric conditions, which significantly impact agricultural production and the global food supply chain (Burnham & Ma, 2016; Paloviita & Järvelä, 2019; Guo *et al.*, 2019). These impacts include reduced crop yields, disruptions in logistics, changes in crop composition, and compromised food quality, all of which intensify food insecurity (Tirado *et al.*, 2013; Wheeler & von Braun, 2013; Aung, & Chang, 2014; Ivanov *et al.*, 2017; Fan *et al.*, 2021; Shah & Otterpohl, 2021). Given the regional variability of these impacts, locally tailored mitigation and adaptation strategies are crucial (Awan *et al.*, 2021; Rahman *et al.*, 2022).

In sub-Saharan Africa, particularly South Africa, the effects of climate change intersect with socioeconomic disparities, exacerbating vulnerabilities in food access and nutrition security (Vermeulen *et al.*, 2012; Myers *et al.*, 2017; Nchanji *et al.*, 2021). South Africa's high Gini Coefficient illustrates this inequality, highlighting how wealthier populations adapt more easily, while poorer communities, especially smallholder farmers, are disproportionately affected (Dennis & Dennis, 2012; Smith, 2020). These farmers rely heavily on rain-fed agriculture and have limited access to resources and markets, increasing their exposure to climate-related shocks such as droughts, floods, and pest outbreaks (Khan *et al.*, 2020; Amelework *et al.*, 2021).

The broader food system is further strained by climate-induced disruptions in production, processing, distribution, and retailing (Ghadge *et al.*, 2019; Guo, 2023), as well as by external shocks such as the COVID-19 pandemic (Rasul, 2021; Omoruyi *et al.*, 2022). In South Africa, recent climate events like floods in KwaZulu-Natal have severely hindered agricultural productivity and food supply chain functionality (Umetsu & Miura, 2023).

Addressing these interconnected challenges requires a systems-thinking approach that integrates climate-smart agricultural practices, supportive policy frameworks, and technological innovation. However, current literature lacks comprehensive assessments of

how climate change affects all stages of the food supply chain in developing countries. This study seeks to fill that gap by exploring smallholder farmers' vulnerabilities, adaptation strategies, and policy needs, particularly in the context of rural South Africa. The objectives of this study are presented in Table 2-1.

Table 2-1: Objectives of the study

To understand the impact of climate change on the food supply chain holistically.
To understand the Impact of climate change on the livelihoods and food security of smallholder farmers and consumers.
To find ways to adapt and mitigate these impacts on smallholder farmers and the entire food supply chain to make them resilient, as well as to understand the policy recommendations.

2.2. Methodology

A systematic review was conducted to assess the effects of climate change on the food supply chain by adhering to the PRISMA-P guidelines (Selçuk, 2019) for systematic reviews and the methodological framework for scoping reviews.

2.2.1 Data Sources

A comprehensive literature search was conducted for this systematic review using the Web of Science, Scopus, and Google Scholar databases. Scopus and Web of Science were used to identify the peer-reviewed articles. This was done to ensure the board coverage of the relevant literature. Pre-defined keywords and exclusion and inclusion criteria were used to ensure that the retrieval of pertinent articles related to the research question was included in the systematic review (Arksey & Malley, 2005).

2.2.2. Search Strategy/ Search Strings

The search strategy aimed to identify studies relevant to the research question (What is the impact of climate change on the food supply chain of smallholder farmers' livelihoods, food security, resilience, and adaptation strategies)? The searches were refined to include results that were published in English only and between 1993 and 2023. The results were assessed by two investigators to ensure an unbiased study with minimal human error. After a rigorous initial systematic search, the investigators double-checked the search results, ensuring that they met the inclusion criteria, as outlined below in section 2.2.

The search strategy employed Boolean operators (And, OR) to refine results based on specific keywords such as "Climate," "Change," "Food Supply Chain," "Agriculture," and "Smallholder Farmers." The search terms "Adaptation Strategies," "Livelihoods," "Food Security," and "Resilience" are used to broaden the search. A total of 20,889 articles were initially identified by applying this search strategy across databases. This vast pool of literature was then carefully screened to include only studies that met the established eligibility criteria, focusing on peer-reviewed publications in English from 1993 to 2023.

The retrieved documents relevant to the search criteria were exported to the QSR NVivo 12 for qualitative data analysis (Dhakal, 2022). NVivo 12 was used to enhance the efficiency, transparency, and rigour of the review process by facilitating data management, thematic analysis, and collaboration (QSR International, 2018). It also supported quality assurance and adherence to the reporting standards. This rigorous approach ensured that the review process was systematic and comprehensive.

The search strings used for the systematic review are mentioned below:

2.2.2.1 Web of Science

TITLE-ABS-KEY (climate AND change AND food AND supply AND chain AND agriculture OR smallholder AND farmers OR adaptation AND strategies OR livelihoods OR food AND security OR resilience) AND (LIMIT-TO (LANGUAGE," English"))

2.2.2.2. Scopus.

Climate AND change AND food AND supply AND chain AND agriculture OR smallholder AND farmers OR adaptation AND strategies OR livelihoods OR food AND security OR resilience AND PUBYEAR > 1992 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE," ar")) AND (LIMIT-TO (LANGUAGE," English")) AND (LIMIT-TO (SRCTYPE," j")) AND (LIMIT-TO (PUBSTAGE," final"))

2.2.2.3. Google Scholar

Climate Change AND Food Supply Chain AND Agriculture OR Smallholder Farmers OR Adaptation Strategies OR Livelihoods OR Food Security Resilience. The search was refined to articles published in English between the period of 1993-2023.

2.2.3. Inclusion and Exclusion Criteria/Selection Process

The eligibility criteria for this review focused on studies addressing the impact of climate change on various aspects of the food supply chain. The outcome variables pertained to the impact of climate change on the different components of the food supply chain. Both qualitative and quantitative research designs were included, provided they were peer-reviewed and published in English. Literature was sourced from the Web of Science, Scopus, and Google Scholar databases. The search was limited to peer-reviewed studies published between 1993 and 2023.

Papers that were not published in English or peer-reviewed were excluded. The exclusion of non-English publications represents a potential limitation of this study, as it may have restricted the inclusion of relevant research conducted in other languages. Papers with only one abstract were excluded. Papers were screened by the researcher for relevance based on the title and abstract relevance to the topic. Papers that focused on Africa and South Africa were included and prioritized over those that focused on other countries. Discrepancies in the relevance of articles were resolved through discussions with the researcher. The full texts of the potentially relevant articles were reviewed to confirm their eligibility. The inclusion and exclusion criteria utilized in this study are summarized in Table 2-2.

From the initial search, 27,249 articles were sourced from Web of Science, 7,232 from Scopus, and 20,500 from Google Scholar. During the abstract screening phase, 10,585 articles were deemed ineligible and were excluded. The full texts of the remaining 10,304 articles were then assessed for further eligibility, leading to the removal of 10,161 articles owing to a lack of relevant information or appropriateness for the systematic review. A total of 143 articles met the eligibility criteria for the study, comprising 26 articles from Web of Science, 20 from Scopus, and 97 from Google Scholar, making a total of 143 articles included in the systematic review (Figure 2-1).

Table 2-2: Inclusion and Exclusion criteria used in the study.

Criteria	Inclusion	Exclusion
Study Focus	Impact of climate change on food supply chain	Studies not addressing climate change impacts on food supply chain
Outcome Variables	Impacts on different components of the food supply chain	Outcomes not related to food supply chain
Research Design	Qualitative and quantitative studies	Non-peer-reviewed studies

Publication Status	Peer-reviewed articles	Non-peer-reviewed articles
Language	Published in English	Not published in English
Publication Date	Published between 1993 and 2023	Published outside the specified date range
Abstract Requirement	Full-text articles	Articles with only an abstract
Screening Process	Relevance assessed by title and abstract	Articles deemed irrelevant during title/abstract screening
Discrepancies	Resolved through discussions with the researcher	N/A
Initial Article Count	27,249 (Web of Science), 7,232 (Scopus), 20,500 (Google Scholar)	10,585 articles excluded during abstract screening

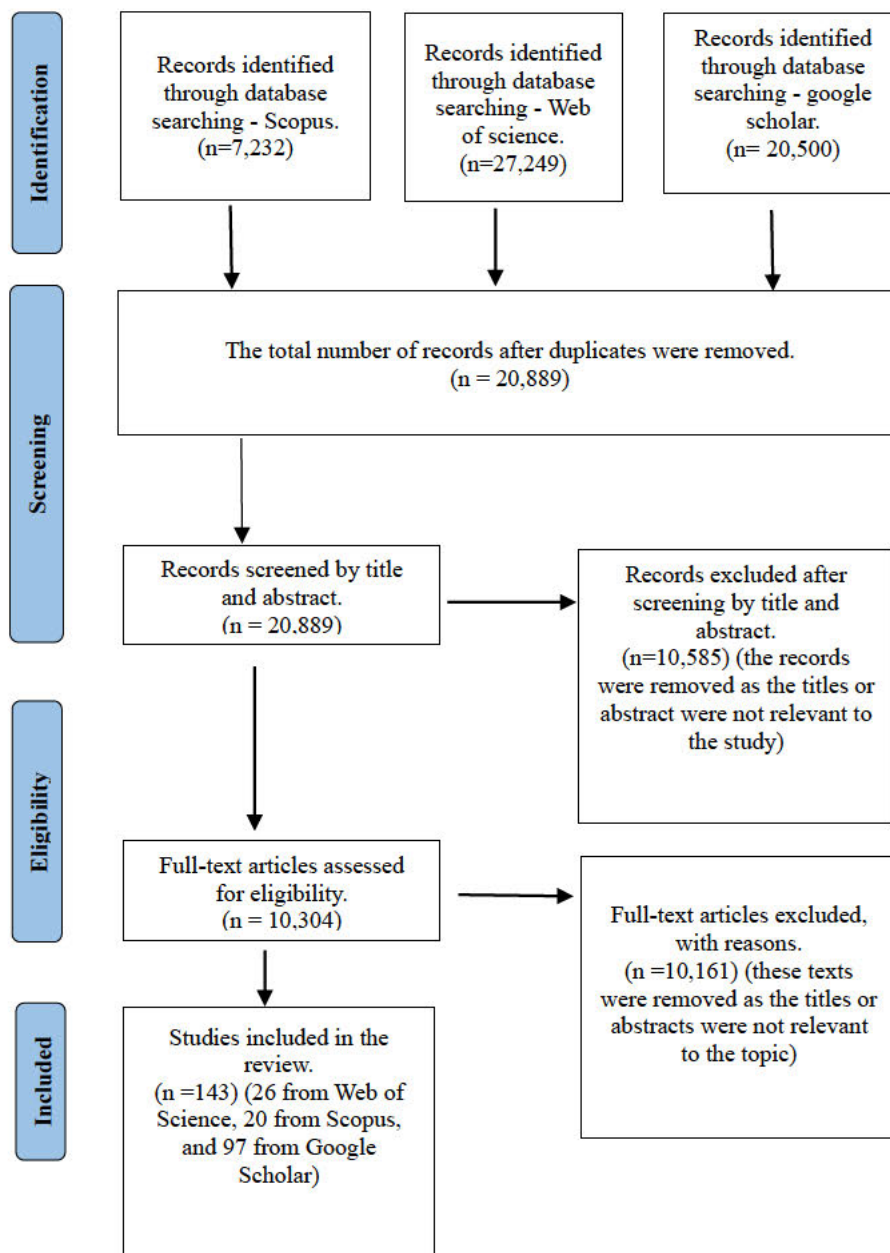


Figure 2-1: PRISMA flow chart showing the literature search procedure for this systematic review.

2.2.4. Risk of Bias Assessment

Each identified study used in this systematic review was assessed for bias using the Joanna Briggs Inventory (JBI) checklist (Munn *et al.*, 2015), as illustrated in Table 2-3. It focused on factors such as the appropriateness of the title, the quality of the abstract, and whether the article had undergone peer review (Moher., 2015). The articles were scanned by the researchers

to determine whether they met the eligibility criteria. The studies were then checked using the Joanna Briggs Inventory (JBI) and PRISMA Guidelines 2020 checklists.

Thereafter, a dual review was conducted by two researchers to reduce selection bias. The authors and journal names were blinded during the review to limit any potential bias. The process outlined above was used to reduce and control for bias in this study. Only the studies that met these high standards were considered in the final analysis. Additionally, the results were reported following PRISMA guidelines to ensure transparency and replicability in the review process (Shamseer *et al.*, 2015). The use of the PRISMA checklist as a guideline prevented bias in reporting (Moher., 2015). This systematic approach allowed for a robust selection of studies that aligned with the objective of the review, to investigate the impact of climate change on various components of the food supply chain of smallholder farmers.

Table 2-3: Joanna Briggs Inventory (JBI) checklist used in the study.

Criteria	Question	Yes	No	Unclear
Eligibility Criteria	Was the study objective clearly defined?	✓		
	Were the inclusion and exclusion criteria clearly defined?	✓		
Sample Size	Was the sample size sufficient to detect a significant difference?	✓		
	Was the sample size based on power calculations or statistical considerations?	✓		
Interventions	Were the interventions clearly described?	✓		
Outcome Measures	Were the outcome measures clearly defined and appropriate?	✓		
	Were the outcomes measured reliably and validly?	✓		
Statistical Analysis	Was the statistical analysis appropriate and clearly described?	✓		
	Was an intention-to-treat analysis conducted?	✓		
	Were appropriate statistical tests used?	✓		
Results & Conclusions	Were the results reported (with confidence intervals and p-values)?	✓		
	Did the study provide an appropriate interpretation of the findings?	✓		
	Were the conclusions supported by the results?	✓		
Bias	Were there any sources of bias identified (e.g., selection bias, performance bias, detection bias)?		✓	
	Were potential biases addressed or minimized?	✓		
Ethical Considerations	Was the study ethically approved (e.g., by an Institutional Review Board or Ethics Committee)?	✓		

2.2.5. Quality Assessment

Quality assessment of the studies found using the three databases was conducted using the PRISMA guidelines and checklist, as shown in Table 2-4 (Shamseer, *et al.*, 2015). This was performed to ensure a transparent systematic evaluation process. The independent reviewer evaluated the quality of each of the articles included in the study and removed articles that were not found eligible using the inclusion and exclusion criteria mentioned in Section 2.2.

The PRISMA guidelines, as seen in Figure 2-1, indicated that the majority of the articles did not fit the scope of work or were of lower quality; therefore, they were not included in the study. The process of assessing the quality of the studies included in the review aimed to enhance the reliability of the study and provide a clearer understanding of the evidence about the topic (Shamseer *et al.*, 2015).

NVivo 12 was selected for its advanced capabilities in managing and analysing large volumes of qualitative data, offering more efficient organisation and coding than tools like Excel or Covidence. Manual duplicate removal within NVivo ensured data accuracy and integrity, and this clarification enhances methodological transparency for all readers (Dhakal, 2022). Once the documents were imported into NVivo 12, themes were created to focus on emerging codes, such as adaptation and mitigation measures, resilience, and the global food system. Matrix coding was employed to identify trends and explore relationships, thus assessing the effects of climate change on the food supply chain. Figure 2-2 illustrates the analytical process used in this study.

Table 2-4: PRISMA Guidelines 2020 Checklist used in the study.

No.	Section/ Topic	Item	PRISMA 2020 Guideline
1	Title	Identify the report as a systematic review, meta-analysis, or both.	1a
2	Abstract	Provide a structured summary of the review, including background, objectives, methods, results, and conclusions.	2a
3	Rationale	Explain the rationale for the review in the context of existing knowledge.	3
4	Objectives	Provide an explicit statement of the review's objectives.	4
5	Eligibility Criteria	Specify the eligibility criteria for considering studies in the review.	5a, 5b

6	Information Sources	Specify all information sources used in the review (e.g., databases, registers, grey literature) with dates of coverage.	6
7	Search Strategy	Present a full electronic search strategy for at least one database, including any filters used.	7
8	Selection Process	Describe the process for selecting studies (screening, eligibility assessment, and inclusion).	8
9	Data Collection Process	Describe the method of data extraction from reports, including information on how data discrepancies were resolved.	9
10	Data Items	List and define all variables for which data were sought (e.g., participants, interventions, outcomes).	10
11	Risk of Bias in Individual Studies	Describe methods for assessing the risk of bias in individual studies.	11
12	Study Records	For each study, provide details about how study records were handled (e.g., study protocol, conflicts of interest).	12
13	Synthesis of Results	Describe the methods used for synthesizing results, including statistical methods (meta-analysis).	13
14	Risk of Bias Across Studies	Assess and describe the potential for bias across studies (e.g., publication bias, selective reporting).	14
15	Additional Analyses	Describe any additional analyses (e.g., sensitivity analyses, subgroup analyses).	15
16	Results	Present a summary of study characteristics and risk of bias within and across studies.	16a, 16b
17	Synthesis of Results	Present the main findings, including the statistical analysis, and potential sources of heterogeneity.	17
18	Risk of Bias in Studies	Discuss how the risk of bias affected the results.	18
19	Funding	Report on the funding sources for the systematic review and any conflicts of interest.	19
20	Discussion	Provide an overall interpretation of the results, considering the limitations of the review and the implications for practice.	20

The process of data analysis is outlined in the flow chart Figure 2-2 below.

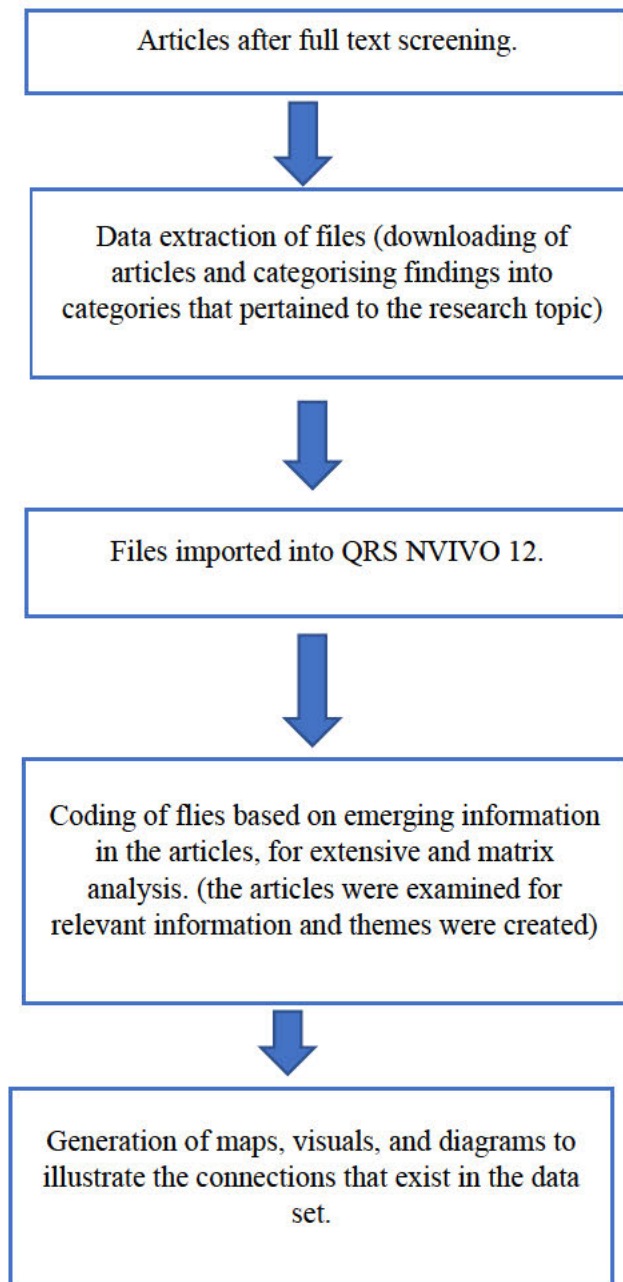


Figure 2-2: The process of data analysis was implemented for the articles that fit the inclusion criteria.

2.2.6. Key themes identified from the NVivo screening process

The themes that emerged from the NVIVO analysis were agricultural production, processing, distribution, retail, post-harvest handling, food safety, consumption, food waste, global food system, adaptation and mitigation/policy, and food security/livelihoods/resilience, as shown in Figure 2-3. These themes guided the results of this systematic review.

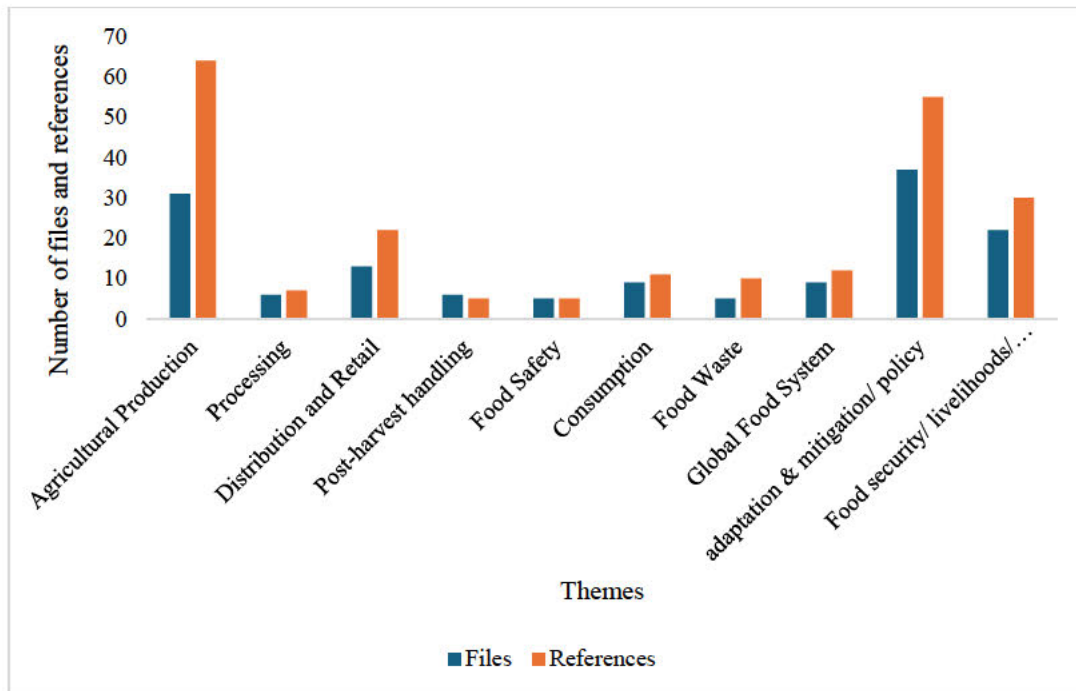


Figure 2- 3: Themes identified derived from the NVIVO analysis (own analysis)

2.2.7. Geographic Location of Studies

This systematic review focused on Africa, with 35 articles covering the continent and 39 articles specifically on Southern Africa. This reflects the region's high vulnerability to climate change and its reliance on agriculture for livelihoods. This focus addresses the critical challenges posed by extreme weather events and disruptions to food systems, highlighting the socio-economic impact of climate change in a region where food security is particularly at risk. Additionally, the review included 47 articles, as seen in Figure 2-4, with global data, enabling comparisons to understand how Africa's challenges align with or differ from global trends. This approach provides valuable insights for tailored policymaking and adaptation strategies in Africa while contributing to a global understanding of climate impacts on food supply chains.

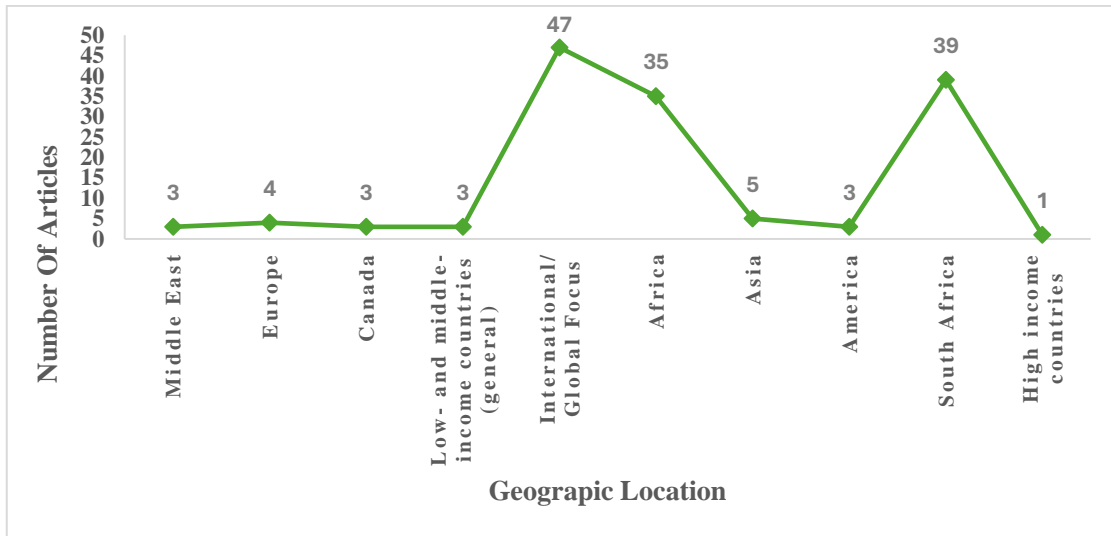


Figure 2- 4: Geographic Location of papers used in the study.

2.3. Results

The systematic review recognized several key findings that emerged from the literature on how climate change affects the food supply chains in South Africa and Africa. It also found key factors that affect the livelihoods and food security of smallholder farmers and consumers in the food supply chain. Insight into the policy recommendations was also recorded to overcome the issues that climate change imposes on the food supply chain. The Results section outlines the findings from the literature used in this review.

a) To understand the impact of climate change on the food supply chain holistically.

This objective focuses on examining the full spectrum of climate change effects on the food supply chain, encompassing all stages from agricultural production, storage, and processing to transportation, retail, and consumption. It seeks to identify how changes in temperature, rainfall patterns, and extreme weather events influence each component of the chain, with particular attention to vulnerabilities in rural and under-resourced contexts. The goal is to gain a comprehensive understanding of the interconnectedness and cumulative stressors within the supply chain.

The key themes that emerged for the impact of climate change on the food supply chain were agricultural production, Processing, Distribution and Retail, Post-harvest handling, Food Safety, Consumption, Food Waste, Food System, adaptation and mitigation, and food security, as exemplified in Figure 2-5.

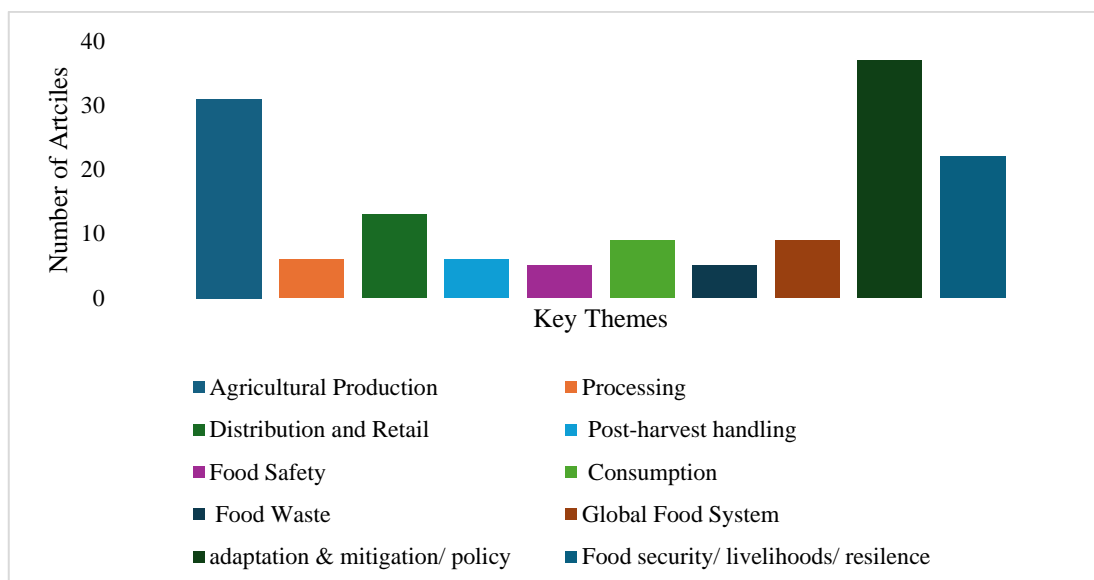


Figure 2- 5: Key themes on how climate change impacts the food supply chain.

The majority of studies (37 studies) focused on adaptation and mitigation strategies and policies as seen in Figure 2-5 above. 31 articles identified that climate change affected the agricultural production sector of the food supply chain. These studies highlighted that due to climate change, there is a 50 % reduction in rain-fed agricultural yields between the years 2000 and 2020 (Challinor *et al.*, 2007; Brown *et al.*, 2009; Musvoto *et al.*, 2015; Bijani *et al.*, 2020) they also indicated that this figure could increase in the future. Climate change is a major threat to agricultural production in Africa and South Africa (Rurinda *et al.*, 2015; Mthembu & Hlophe, 2021). Many studies have also underscored the extensive range of impacts climate change is expected to have on the agricultural sector and crop yield of crops (Castro *et al.*, 2016; Shisanya & Mafongoya, 2017; Mkuhlani *et al.*, 2022). Studies have also emphasized the implications for water resources, food security, and the ecosystem (Gbetibouo *et al.*, 2010; King *et al.*, 2017; Ribeiro & Rodriguez,2020).

Distribution and retail were identified in 13 studies as key sectors affected by climate change. Climate change worsens vulnerabilities, which affect networks (Dasaklis & Pappis, 2013; Odimegwu, 2022). The COVID-19 pandemic has worsened these challenges, as food shortages have led to increased prices (Khan *et al.*, 2020; Mishra *et al.*, 2021; Omoruyi *et al.*, 2022).

Nine studies identified consumption as a sector affected by climate change (Figure 2-5). Research has found that as extreme weather events negatively affect crop yields, there is a decrease in the quality and quantity of the crop produced (Ronquest-Ross *et al.*, 2015; Mugambiwa & Tirivangasi, 2017). This negatively affects the availability and price of food,

thereby negatively affecting consumers' consumption and food security in the food supply chain (Amoah & Simatele, 2021; Tshikovhi & Wyk, 2021).

Nine studies showed that the global food system is affected by climate change. Studies have shown that extreme weather events that cause delays in the supply chain affect the world (Gregory *et al.*, 2005; Khee *et al.*, 2014; Sithole, 2019; Paganini *et al.*, 2020; Dinesh *et al.*, 2021). This is because exports are affected by quality and price hikes. This study states that this has a ripple effect on the global flow of food globally (Porter *et al.*, 2016; Nelson *et al.*, 2016). This underscored the devastating consequences of climate change on food security, aligned with the concerns articulated by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2021).

Six studies considered the processing sector of the food supply chain was considered by 6 studies as affected by climate change. They highlighted that climate change disrupts the production, transportation, and storage of produce (Kurukulasuriya & Mendelsohn, 2008; Singh & Capri, 2014; Duchenne-Moutien & Neetoo, 2021; Romero-Perdomo *et al.*, 2022). This causes bottlenecks in the food supply chain (Reza & Sabau, 2022; Zia *et al.*, 2022). It was also found that extreme weather events, such as floods, damage storage and processing facilities, which leads to price hikes and delays (Paloviita & Järvelä, 2019; Meyer, 2020).

Five studies have considered the effect of climate change. Studies have highlighted that extreme weather events cause crop loss, leading to an increase in food waste (Simba *et al.*, 2017; Amicarelli, & Bux, 2020; Machate, 2020). It has also been noted that extreme temperature changes affect the shelf life of crops, thereby contributing to food waste (Oelofse *et al.*, 2018; Angula *et al.*, 2022; Semenya, 2023).

Finally, post-harvest handling was recorded by six studies as an effect of climate change, and five studies reported food safety as a concern in the food supply chain that is affected by climate change, as illustrated in Figure 2-5. It was noted that the delays caused by climate change effects limit the availability of harvested crops, which causes problems in post-harvesting processes (Bezares *et al.*, 2021; Assan, 2022; Gerken & Morrison, 2022). The increase in food pathogens, contamination, and waterborne diseases caused by climate change affects the production and consumption processes in the food supply chain as the demand and confidence of the consumer decreases, thus making food safety a concern (Lake & Barker, 2018; Berhanu & Wolde, 2019; Mazi *et al.*, 2023; Kwame *et al.*, 2022; Luo *et al.*, 2022).

b) To understand the Impact of climate change on the livelihoods and food security of smallholder farmers and consumers.

This objective explores how climate variability affects both the economic well-being and food access of smallholder farmers who often rely on rain-fed agriculture and the communities they serve. It examines key issues such as income instability, crop failure, food affordability, and nutritional outcomes, particularly in vulnerable populations. The intent is to assess how these challenges contribute to broader concerns of poverty, inequality, and social exclusion in rural and peri-urban settings.

The review concluded that small-scale farmers in Africa, particularly those in South Africa, are a major part of the food supply chain and disproportionately vulnerable to the effects of climate change. This also affects the livelihoods of consumers. The effects of climate change on the livelihood and food security of smallholder farmers and consumers are shown in Figure 2-6.

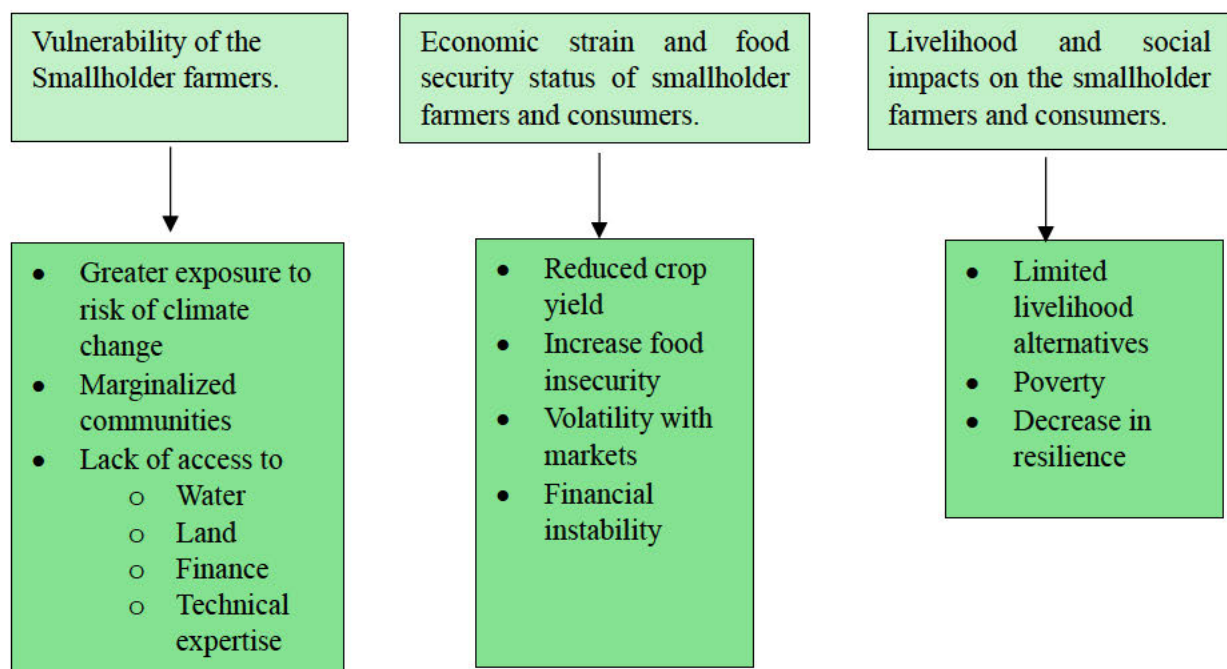


Figure 2- 6: Impacts of climate change on the livelihoods and food security of the smallholder farmers that emerged from the review.

As illustrated in Figure 2-6, the findings from the literature review highlight that the farming sector particularly smallholder vegetable farming, which marks the start of the food supply chain is highly vulnerable to the impacts of climate change. These vulnerabilities are especially pronounced among farmers from marginalized communities, whose limited access to resources undermines their adaptive capacity (Ncube *et al.*, 2016; Hank *et al.*, 2019).

Smallholder vegetable farmers are at heightened risk of exposure to climate variability due to their dependence on natural rainfall and their constrained access to irrigation systems, climate-smart technologies, and extension services (Ghadge *et al.*, 2019; Oluoko-Odingo & Ayiomba, 2020; Patrick *et al.*, 2021). In both South Africa and the broader African context, barriers such as inadequate water access, financial exclusion, insecure land tenure, and limited technical expertise further intensify their exposure to climate shocks (Bigliardi *et al.*, 2022; Manoj *et al.*, 2023).

The cascading effects of climate change were found to detrimentally impact not only vegetable producers but also consumers, with significant implications for both food security and the economy. For instance, unpredictable weather patterns and reduced crop yields common in vegetable farming have been linked to increased market volatility and disruptions in supply chains (Farooq *et al.*, 2022; Hedlund *et al.*, 2022). Declines in agricultural productivity ultimately led to reduced availability of vegetables, rising food prices, and diminished household food access, particularly in rural and low-income urban communities (Vermeulen *et al.*, 2012; Manoj *et al.*, 2023).

Financial instability, driven by reduced and unreliable yields, further undermines smallholder vegetable farmers' resilience and sustainability within the food system (Tumwesigye *et al.*, 2019; Schilling *et al.*, 2020). These impacts increase the likelihood of food unaffordability and hunger, particularly among vulnerable populations (Oelofse & Nahman, 2012; Hendriks & Olivier, 2015; Akil & Ahmad, 2023). Figure 2-6 also illustrates the broader social and livelihood implications of climate-induced supply chain disruptions. Smallholder vegetable farmers, who often lack viable alternative income streams, face heightened livelihood insecurity due to the centrality of agriculture in household economies (Musango & Peter, 2007; Averbeke & Khosa, 2018; Mthembu & Hlophe, 2021).

Moreover, the persistence of climate shocks without adequate adaptation responses is projected to exacerbate rural poverty and deepen food insecurity (Olabanji *et al.*, 2020; Afokpe *et al.*, 2022). The limited supply of fresh produce like vegetables elevates food prices and places an additional burden on already vulnerable communities (Masipa, 2017; Chersich & Wright, 2019; Teresa, 2021; Guo, 2023). Without timely and targeted interventions, climate change will continue to erode the resilience of both producers and consumers, worsening national food security indicators and impeding progress toward climate-resilient agricultural systems (Myers *et al.*, 2017; Mohtar & Fares, 2022; Guo, 2023).

c) To find ways to adapt and mitigate these impacts on smallholder farmers and the entire food supply chain to make them resilient, as well as to understand the policy recommendations.

This objective seeks to identify practical strategies that smallholder farmers and stakeholders along the food supply chain can adopt to reduce their vulnerability to climate change. It evaluates existing and potential adaptation techniques (such as climate-smart agriculture) and mitigation efforts (like emissions reduction and sustainable land use), alongside an analysis of national and international policy frameworks. The aim is to recommend targeted, evidence-based interventions that enhance resilience and promote long-term sustainability in food systems.

The studies identified in the review presented a diverse range of adaptation and mitigation strategies in response to climate change globally, as illustrated in Figure 2-7. This figure quantifies the number of articles that discussed each strategy, revealing a concentration of scholarly attention in specific areas. Notably, climate-smart agricultural practices were the most frequently cited (seven articles), followed by agricultural transformation and sustainable land use (six articles). Other commonly discussed strategies include strengthening of the supply chain, public health and livelihoods, and infrastructure resilience, each cited in four articles (Suebsombut *et al.*, 2017; Molieleng *et al.*, 2021; Chen & Sun, 2022).

These strategies vary in focus and scale, ranging from production-level interventions to system-wide transformations. For instance, climate-smart agriculture encompasses innovations in farming techniques, while supply chain strengthening and public health considerations reflect broader structural and socio-economic dimensions. Additional strategies mentioned include resilience in food systems, water management, improved waste management, and post-harvest handling improvements (Ramirez-Villegas *et al.*, 2012; Klausbruckner *et al.*, 2016; Baninla *et al.*, 2022; Mwadzingeni *et al.*, 2022).

Figure 2-7 offers a useful visual summary, but it is important to note that the strategies are not mutually exclusive and often intersect in practice. Although presented as distinct categories, many of these approaches are complementary and best understood as part of an integrated adaptation framework. For example, investments in infrastructure resilience may simultaneously enhance post-harvest handling and food system stability. The inclusion of examples from the South African context, such as community-led sustainable land use or regional climate-smart initiatives, would further strengthen the connection between the strategies reviewed and the empirical context of this study.

Overall, this review underscores the need for multifaceted, context-sensitive adaptation pathways that integrate agricultural innovation, institutional support, and policy reform to enhance the resilience of food systems in climate-vulnerable regions (Brouder & Gomez-Macpherson, 2014; Hecht & Neff, 2019; Kaudia *et al.*, 2022).

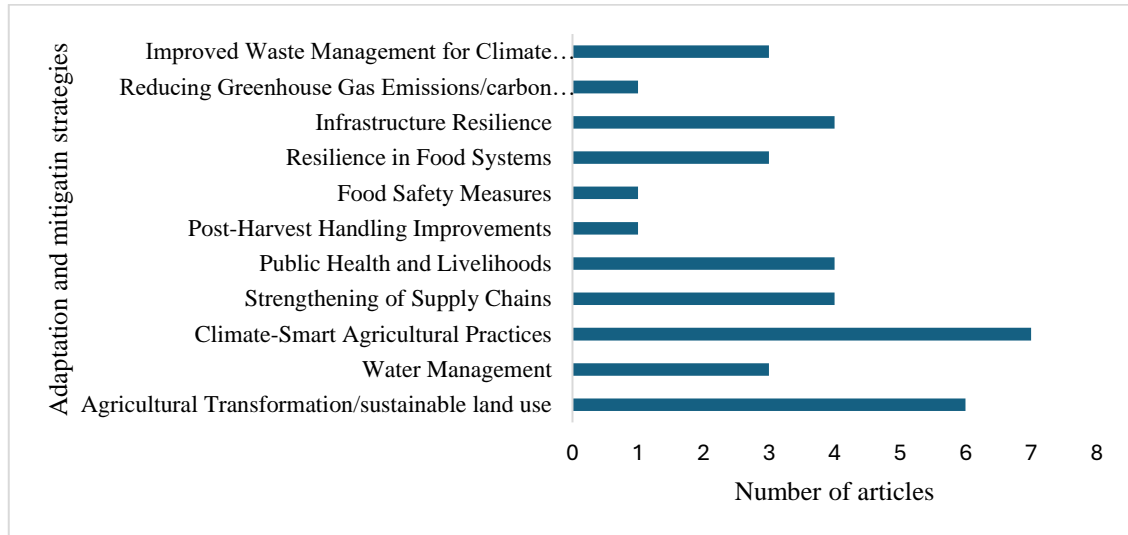


Figure 2- 7: Adaptation and mitigation measures that emerged from the review.

d) Policy recommendations

A wide range of key policy recommendations was highlighted in the reviewed studies, with particular relevance to improving the resilience of vegetable farming systems, especially those managed by smallholder farmers. The literature reveals that climate change affects all nodes of the food supply chain, but smallholder vegetable farmers, who form the backbone of the production sector, are among the most vulnerable. As shown in Figure 2-8, two prominent policy themes emerged: enhancing climate information systems and increasing support for farmers.

Eleven studies emphasised the need for policies aimed at improving access to accurate, localised climate information, which is crucial for vegetable farmers making time-sensitive planting and harvesting decisions. Additionally, eight studies advocated for comprehensive policy frameworks to support smallholder farmers, highlighting the need for financial assistance, extension services, and access to climate-resilient technologies tailored to vegetable production (Lengnick *et al.*, 2015; Burnham & Ma, 2016; Chandra *et al.*, 2018; Thow *et al.*, 2018; Chakwizira, 2019; Wyk, 2022; Osei *et al.*, 2023).

Further policy recommendations included the integration of climate change adaptation into national agricultural policies (five studies), investment in climate-resilient infrastructure such

as irrigation systems and cold storage (four studies), the promotion of public-private partnerships to enhance supply chain resilience (three studies), and international cooperation to address trade vulnerabilities (three studies) (Zinyengere *et al.*, 2013; Zavala-Alcívar *et al.*, 2020; Ayanlade *et al.*, 2022; Lee & Gambiza, 2022; Murken & Gornott, 2022).

Collectively, these policy directions highlight the urgent need for coordinated, targeted interventions that prioritise the unique needs of smallholder vegetable farmers, who are central to food security in both rural and urban areas of South Africa and the broader African continent.

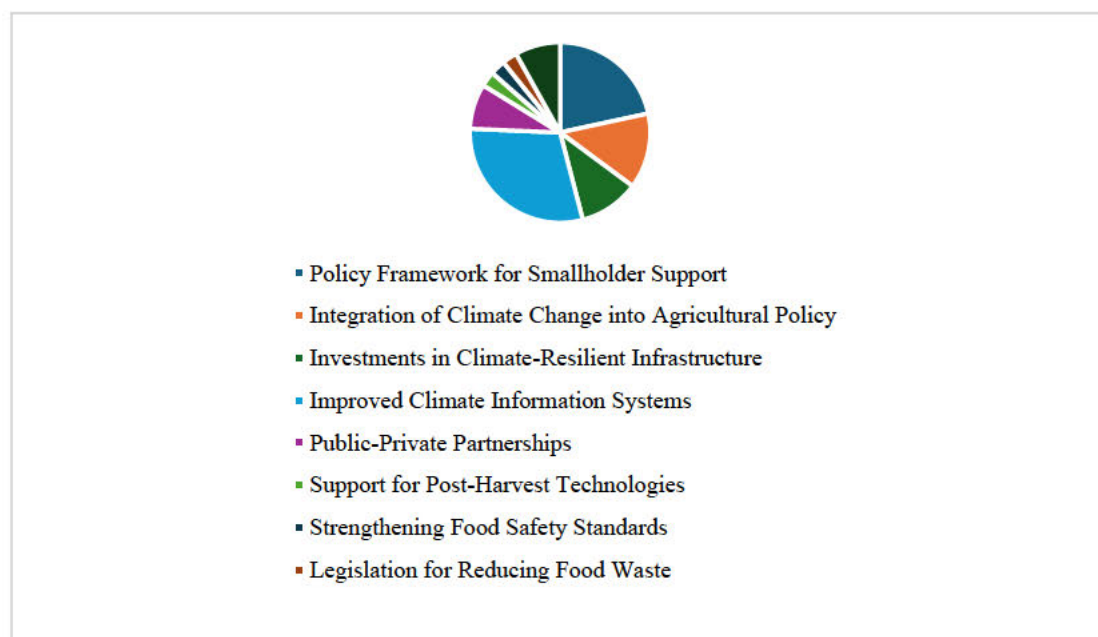


Figure 2- 8: Policy recommendations from the reviewed articles.

In summary, research on improved data collection systems and climate adaptation has been emphasized for better decision-making. The policy recommendations of the reviewed studies provide an inclusive framework to ensure sustainability across the food supply chain.

2.4. Discussion

This systematic review examined various dimensions of the existing literature on the impact of climate change on food supply chains, with a particular focus on South Africa and the broader African context. Key challenges identified include rising temperatures, more frequent extreme weather events, and smallholder farmers' reliance on rain-fed agriculture, all compounded by limited resources and financial constraints (Kazembe *et al.*, 2020; Khan *et al.*, 2020; Daniell & Tonder, 2023). These factors exacerbate food insecurity by driving up food prices through reduced crop yields, highlighting an urgent need to adjust both production and consumption patterns (Terdoog & Feola, 2016; Odimegwu, 2022; Manoj *et al.*, 2023).

External shocks, such as the Russian invasion of Ukraine, further strain global food supply chains and exacerbate nutritional challenges across Africa (Jayathilakan *et al.*, 2018; Hatab, 2022; Sánchez *et al.*, 2022). These challenges are especially pressing for vegetable farming, which is highly sensitive to changes in weather patterns, pest outbreaks, and water availability, issues particularly relevant to the smallholder vegetable farmers in rural KwaZulu-Natal.

The review underscores the critical importance of building sustainable food supply chains that are resilient to these disruptions (Parry *et al.*, 2005; Dasaklis & Pappis, 2013; Pittelkow *et al.*, 2015; Paloviita & Järvelä, 2019). Notably, climate change impacts all segments of the food supply chain, from production to post-harvest handling and consumption (Vermeulen *et al.*, 2012; Rathgens *et al.*, 2020). This is also evidenced in Saudi Arabia and other regions, where climate change has reduced crop viability (Rahman *et al.*, 2022). In South Africa, this has had significant implications for key vegetable crops such as tomatoes, spinach, and cabbage.

Climatic stressors such as shifting rainfall patterns, increased temperatures, and pest invasions like the fall armyworm have had detrimental effects on vegetable yields, directly threatening food security (Nhemachena & Hassan, 2007; Amelework *et al.*, 2021). Vegetables, being more perishable and water-intensive, are particularly vulnerable to these disruptions, underscoring the need for targeted interventions.

In addition to environmental factors, systemic issues such as limited technological access, poor infrastructure, and volatile markets also disrupt vegetable production cycles and weaken the food supply chain (Rurinda *et al.*, 2015; Scherer & Verburg, 2017; Mkhulani *et al.*, 2022; Ruwanza *et al.*, 2022). These limitations are particularly severe for smallholder vegetable producers who lack the institutional support and capital to adapt effectively (Blanc, 2012; Berti & Mulligan, 2016; Müller *et al.*, 2011).

Climate-smart agricultural practices emerged in the literature as key policy solutions for strengthening resilience. These include crop diversification, pest-resistant varieties, and efficient irrigation methods (Tirivangasi, 2018; Mensah *et al.*, 2021; Vignola *et al.*, 2022). In the context of South Africa, the promotion of climate-resilient vegetables, such as amaranth and Swiss chard, alongside improved water use technologies, could significantly enhance smallholder adaptability (Schmidhuber & Tubiello, 2007; Tubiello & Howden, 2007; Willett, 2021; Pereira & Hawkes, 2022; Oduniyi & Sylvia, 2019).

Technological interventions and government support, including training and incentives for farmers, are crucial in enabling widespread adoption of such practices (Ziervogel *et al.*, 2014;

Ncube *et al.*, 2016; Dardonville *et al.*, 2020). These interventions must be context-specific, considering the unique challenges faced by rural vegetable farmers.

Moreover, climate change also intensifies post-harvest losses, especially in perishable crops like vegetables. Disruptions caused by the COVID-19 pandemic such as transport and storage failures, have further exposed these weaknesses (Mendelsohn, 2009; Atwoli, 2022; Omoruyi *et al.*, 2022). This reinforces the importance of investing in cold chain infrastructure and market access for vegetable producers.

The literature also highlights rising food prices, shifts in consumer preferences, and reduced access to nutritious foods as broader consequences of climate disruptions (Parfitt *et al.*, 2010; Umar, 2023). In vegetable farming, these challenges threaten both producer livelihoods and consumer health, particularly among low-income populations.

To address these concerns, policy recommendations from the reviewed studies include improving food governance, developing post-harvest technologies, and enhancing waste management systems critical areas for the vegetable supply chain where perishability and spoilage are major issues (Conway *et al.*, 2015; Ahenkan, 2019; Grote *et al.*, 2021; Dunjana *et al.*, 2022). Policies should also promote sustainable production and reduce input dependency, particularly for smallholder vegetable farmers.

Finally, while much of the reviewed literature uses broad terms such as "agriculture" or "smallholder farming," it is evident that the vegetable sub-sector faces unique vulnerabilities. Addressing this literature gap by highlighting the underrepresentation of vegetable-specific insights helps clarify the focus of this study and reinforces the need for tailored adaptation strategies for smallholder vegetable farmers in South Africa (Hendriks & Olivier, 2015; Masipa, 2017; Kochan & Nowicki, 2018).

2.5. Conclusion

This systematic review set out to investigate the multifaceted impacts of climate change on the food supply chain in South Africa and the broader African region. The review specifically examined the nature of climate-induced challenges, their effects on both producers, especially smallholder vegetable farmers, and consumers, as well as the adaptation and mitigation strategies proposed or implemented in the literature. It also considered policy recommendations aimed at strengthening food system resilience.

Findings reveal that climate change disrupts every stage of the food supply chain from production and processing to distribution and consumption, through extreme weather events,

temperature changes, pest invasions, and erratic rainfall patterns. These disruptions result in crop damage and shortages, driving up food prices and undermining both the livelihoods of smallholder farmers and the food security of vulnerable populations.

While the review identified numerous policy and technical strategies, such as climate-smart agriculture, improved infrastructure, and post-harvest technologies, it also exposed significant gaps. Most notable is the limited focus on vegetable-specific farming systems and the lack of targeted, coordinated support for smallholder farmers. Additionally, the absence of integration across sectors like agriculture, water, energy, and food safety was found to hinder effective resilience-building. The need for equitable resource allocation and knowledge-sharing across developing countries, including South Africa, remains critical.

To further strengthen the food supply chain's resilience, especially for vegetable producers, more research is needed into the roles that market systems, gender dynamics, and local governance structures play in shaping adaptive capacity. These areas remain underexplored yet hold significant potential for informing more context-specific and inclusive climate responses.

By identifying what is known and, crucially, what remains uncertain, this review provides a foundation for the empirical chapters to follow. These next chapters will delve into the lived experiences of smallholder vegetable farmers in KwaZulu-Natal, providing grounded insights into how climate change is affecting their practices, perceptions, and resilience strategies. In doing so, the thesis moves toward proposing integrated, farmer-informed policy interventions that are both feasible and impactful.

2.6. Declarations

a. Author Contribution

Conceptualization: M.N., D.N., and M.S.C.N.; methodology: M.N., D.N., R.S., and M.S.N.; validation: M.N., D.N., R.S., and M.S.N.; writing—original draft preparation: M.N., D.N., R.S., and M.S.N.; writing—review and editing: M.N., D.N., R.S., and M.S.N.; supervision: M.S.N. and D.N. All authors have read and agreed to the published version of the manuscript.

The work was written in complete form by Merishca Naicker, with revisions and reviews by Denver Naidoo Mjabuliseni Simon Ngidi, and Rob Slotow.

b. Conflict of interest

No potential conflict of interest was reported by the authors.

c. Ethics approval and consent to participate.

Not applicable

d. Funding

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CHAPTER 3

MATERIALS AND METHODS

3.1. Introduction

This chapter provides an overview of the study area, data collection processes, and the methods employed in the research. The chapter starts with a description of the study area, KwaZulu Natal Province, offering background information on the region and data gathered. Additionally, the chapter includes details about the models applied in the study. This chapter provides a brief overview of the materials and methods utilized in the overall study, whereas in-depth methods and materials for each objective is provided in chapters 4-7 below.

3.2. Description of study area

The study was conducted in KwaZulu Natal (KZN) which is the eastern most province of South Africa. It is a subtropical coastline with grasslands and the Drakensberg Mountain range which is situated in the western part of the province. The province has a diverse topography that includes coastal plains, midlands, and mountainous areas, resulting in varied agro-ecological zones. This diversity influences the type of crops grown, the farming systems adopted, and the degree of exposure to climate-related risks such as droughts, floods, and soil erosion. The province consists of 11 districts as illustrated in Figure 3-1. The province is approximately 92,100 Km², and the population of the province is estimated to be 11,513,575 as per STATSA, 2021.

The province is largely rural. The province's smallholder vegetable farmers are predominantly located in rural districts such as uThukela, uMzinyathi, Zululand, and Harry Gwala. These areas are characterised by limited infrastructure, lower income levels, and high dependence on rain-fed agriculture. In contrast, districts like eThekweni and uMgungundlovu exhibit more commercial activity and better access to markets and extension services. This intra-provincial variation means that smallholder farmers face different levels of vulnerability and resilience depending on their location.

Understanding these regional differences is essential to contextualising the findings and assessing their broader applicability. By capturing this diversity, the study enhances the relevance of its sampling strategy and ensures that the findings are not only grounded in a specific context but also informative for other similarly diverse settings in South Africa and beyond.

KwaZulu Natal has agricultural land that produces mainly grain and seed crops. These crops vary based on the climate, price, demand, and supply. The majority of the region's inhabitants had moved in search of work, leaving the elderly to care for their grandchildren. A wide variety of agricultural practices are present in the province such as smallholder, subsistence and commercial farming. Major agricultural activities found in the region include grain, fruit, and vegetable farming as well as sugarcane production (IDP, 2020).

The summers are warm with summer rainfall (KwaZulu Natal Municipalities, 2023). The Farms are located inland, and they use the local river sources for irrigation purposes. There is a vast range of seasonal vegetables that are grown by the farmers in the region (Le & Vu, 2022; Anekwe *et al.*,2024). The main supply outlet for the farmers is the Clairwood Fresh Produce market. The main income source of the farmers is from farming and the labour force is from the surrounding areas (Hlatshwayo *et al.*, 2023).

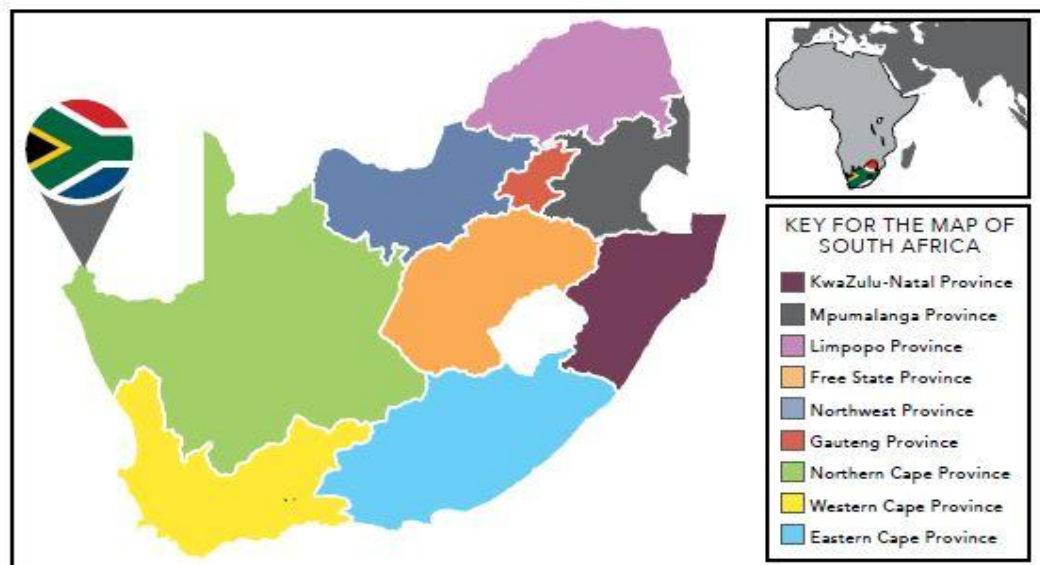


Figure 3 - 1: Map of South Africa showing the study province (KwaZulu Natal) used in this study. Source: <https://images.app.goo.gl/EMJFwMfb9UTi1PAA>

3.3. Research Design

The research design is a plan that provides a framework for the research and outlines steps to take for the research to be successful. The research design is derived from the research problem, it provides insight into what the study tends to investigate (Maxwell,2019; Thornhill & McCluskey, 2023). A mixed-method approach was utilised to investigate the impact of climate change on the food supply chain and livelihoods of smallholder farmers in rural KwaZulu Natal Province. A mixed-methods approach is a methodology used for conducting

research that involves collecting, integrating, and analysing quantitative and qualitative data (Creswell & Creswell, 2021). A mixed method provides strengths that counterbalance the weaknesses of both qualitative and quantitative research.

By using both qualitative and quantitative data, the researcher was able to get a better understanding of the problem and address the key objectives effectively. This design is particularly suitable given the complex and multidimensional nature of the research questions, which explore the impacts of climate change on the food supply chain and smallholder vegetable farmers in KwaZulu Natal.

Quantitative methods, such as structured surveys, provide measurable evidence on the prevalence of climate-related challenges, patterns in adaptation practices, and the socioeconomic status of farming households. However, a purely quantitative approach would not adequately capture the nuanced realities and lived experiences of smallholder farmers, particularly in diverse agro-ecological and socio-economic contexts.

Therefore, qualitative methods, including key informant interviews and focus group discussions, were incorporated to enrich the interpretation of numerical findings. These tools allow for a deeper understanding of farmers' perceptions, coping mechanisms, and institutional or cultural barriers to adaptation. This interpretive depth is essential to explaining the "how" and "why" behind the trends observed in the quantitative data.

The integration of both methods enhances the validity of the findings and allows for a more holistic exploration of the research problem, ensuring that both statistical patterns and contextual narratives are represented. As each empirical chapter focuses on different aspects of the food supply chain, the mixed methods design provides the flexibility needed to address these varied dimensions effectively (Creswell & Poth, 2020). To verify these objectives, interviews, and discussions were conducted with the identified smallholder farmers. A qualitative research method was used since it is a holistic approach. This method was useful as the aim was to focus on the respondent's experiences. For this research, purposive sampling was utilized. The key informants were recommended by the extension officer in the areas. The researcher interviewed farmers who were helpful and positively contributed to the study. Content analysis was applied to analyse the data collected. The KwaZulu Natal (KZN) province was chosen as the study area due to its significant agricultural output, encompassing major crops such as sugarcane, maize, and subtropical fruits, along with its documented vulnerability to extreme weather conditions. To minimize selection bias, the research included smallholder farmers across the entire province.

3.4. Data collection method

The study utilized a qualitative and quantitative research methodology. Data collection occurred from December 2023 till March 2024. Ethical clearance was acquired from the Human Social Science Research Ethics Committee (HSSREC)—HSSREC/00005925/2023.

Data on demographics, agricultural production, food supply chain in KwaZulu Natal, climate change information, income of smallholder farmers, Perceptions of climate change on food security by the smallholder farmers, Household Food Insecurity Access Scale (HFIAS), factors influencing the choice and level of adaptation strategies among the smallholder farmers and Climate Smart Agricultural Practices (CSA) used by smallholder farmers was collected from the questionnaire administered. Simple random sampling to ensure a diverse and unbiased representation of smallholder vegetable farmers in rural KwaZulu-Natal was used. A 95% confidence interval and a 5% margin of error were employed. This sampling technique is valued for its simplicity and objectivity, as it ensures each individual in the population has an equal chance of being selected (Asrial *et al.*, 2022). It is especially effective when the goal is to generate findings that are generalisable to the broader population (Tanaka & Miki, 2022).

Prior to full-scale data collection, the survey questionnaires were pre-tested with a small group of smallholder vegetable farmers (n=10) from Ugu district, not included in the main study. This pilot exercise helped refine the clarity, wording, and structure of the questions, ensuring that the instrument was both culturally relevant and easily understood by the target population. Feedback from the pilot was incorporated to enhance the questionnaire's reliability and content validity.

For the qualitative component, focus group participants were purposively selected to ensure representation across gender, age, and geographic location within the selected districts. This sampling strategy aimed to capture a diverse range of experiences and perspectives regarding climate change and food supply challenges.

A total of twelve focus group discussions were conducted, each comprising 8–10 participants chosen from the sample population used in the questionnaires. These sessions were audio recorded with participant consent, and subsequently transcribed verbatim to preserve the integrity of the data. Field notes were also taken to supplement the transcripts and capture non-verbal cues and group dynamics.

The data was collected from 200 smallholder farmers in the region, randomly selected from a sampling frame of 2530 farmers, all of whom were affiliated with local agricultural

organizations or market operators, to ensure data reliability and traceability. While unregistered farmers were excluded, this was a practical decision based on accessibility and logistical feasibility. The registered farmers were considered broadly representative, as they shared key characteristics with informal producers (Beharielal *et al*, 2022). Although this may introduce some bias, the choice was justified to maintain data quality and ensure effective fieldwork. Although this selection method excluded unregistered farmers, it was believed that the registered farmers shared similar characteristics (Beharielal *et al.*, 2022), ensuring a comprehensive representation of the region's smallholder farmers.

This selection strategy was guided by both statistical and contextual considerations. From a statistical perspective, a sample size of 200 is sufficient to allow for meaningful quantitative analysis, including subgroup comparisons and generalizable insights within the study area. Given the finite population size of 2,530, this sample yields a margin of error of approximately $\pm 6.5\%$ at a 95% confidence level, which is acceptable for social science research.

Contextually, focusing on farmers affiliated with agricultural organizations and market structures ensures that respondents are actively engaged in farming activities and integrated into the food supply chain, making them relevant units of analysis for a study exploring resilience in food systems. This also increased the reliability of responses, as these farmers were more likely to have experience with institutional support, market dynamics, and climate-related challenges.

Moreover, random sampling within this defined frame helped to reduce selection bias and ensure that the sample reflected a diverse cross-section of smallholder vegetable farmers in terms of geographic location, farming scale, and demographic characteristics. This enhances the internal validity of the findings and improves the generalizability to similar farming populations within the region.

Data on market participation by smallholder farmers and the effect of climate change on income share was collected from 22 key informative interviews. Lastly, the farmer's challenges and perspectives about the impact of climate change on their agricultural production and involvement in the food supply chain were collected from the Focused Group Discussions (FGDs) that were conducted with 12 groups of farmers. Purposive sampling was used to select the participants. Purpose sampling is efficient, allows the researcher to choose a target audience, is cost-effective and provides in-depth information (Creswell & Poth, 2020; Pons &

Silva, 2021). The main focus of the study was to identify the impact of climate change on the food supply chain of smallholder farmers in KwaZulu Natal.

3.5. Methods of data analysis

The collected questionnaires were carefully examined for accuracy and completeness when the fieldwork had concluded. To ensure a thorough investigation, a variety of statistical and data science methods were used. In particular, the immense dataset was efficiently managed by combining statistical methods with qualitative modelling techniques. A summary of the methods used for each objective of the study is provided in Table 3-1 below.

The quantitative data was analysed by the use of STATA statistical software, version 18, IBM SPSS (Statistical Package for the Social Sciences), version 28, Excel and NVivo 12. The qualitative data was analysed by using Excel. To compile the data and make insightful deductions, descriptive statistics and pertinent quantitative models were utilized. The descriptive statistics were analysed to condense the key socio-economic characteristics of the surveyed smallholder farmers. The socio-demographic factors included age, gender, position in household, household size, education level and marital status.

The key informative interviews included questions that focused on how climate change influenced market participation, quality and quantity of produce and general information on the food supply chain. The focused group discussion focused on the farmer's experiences, challenges and adaptation methods associated with climate change. This data was analysed using NVivo 12, version 12 for the qualitative component. NVivo software was used to conduct thematic coding through an inductive approach, allowing themes to emerge organically from the data. To ensure methodological rigour, inter-coder reliability was assessed by having a second researcher independently code a portion of the transcripts, with discrepancies resolved through discussion. Coding categories were refined iteratively, ensuring they remained closely aligned with the research questions and provided rich, contextual insights into the experiences of smallholder farmers.

To Understand the food supply chain in Kwazulu Natal, the quantitative data was analysed using SPSS and the qualitative data derived from the key informant interviews was analysed using NVivo 12, version 12. A more detailed explanation is found in Chapter 4 to avoid duplication.

This study used many econometric analytical tools to achieve the results of the specific objectives. The Seemingly Unrelated Regression (SUR) model and a Box-Cox regression

model with a control function approach were used to evaluate the influence of climate change perceptions on the smallholder farmers' incomes. While Seemingly Unrelated Regression (SUR) was used to account for correlations across multiple dependent variables. Box-Cox transformations addressed data skewness, enhancing model fit, and probit and ordered probit models assessed the likelihood of adopting adaptation strategies. This multi-method design ensured a nuanced and coherent interpretation of the data. This method made it easier to obtain useful information about intricate agricultural processes, as Tzortzios *et al.* (2019) describe. This method was perfect for the study as it allows for controlled variables. The Seemingly Unrelated Regression (SUR) model was chosen over Ordinary Least Squares (OLS) because it allows for the simultaneous estimation of multiple equations with different dependent variables that may have correlated error terms. This is particularly useful in the context of this study, where variables such as income, yield loss, and adaptation strategies are likely influenced by common unobserved factors. By accounting for these correlations, SUR provides more efficient and accurate estimates than OLS, enhancing the reliability of the results. This approach also supports a more holistic understanding of interconnected outcomes, which is essential for informing effective policy and intervention strategies.

The reasons why the above tools were used are discussed in Chapter 5 to prevent repetition of the information. By integrating these diverse analytical tools, the study was able to capture both statistical trends and lived experiences, offering a nuanced understanding of the climate-related vulnerabilities and adaptive capacities of smallholder vegetable farmers in KwaZulu-Natal.

The Multivariate Probit model was used to examine the factors that influence farmers' selection of multiple adaptation strategies, exploring the likelihood of adopting several strategies at once and considering the interconnections between them. The model extends the standard probit framework to multiple equations, providing a more robust method for analysing adoption behaviour in agriculture (Vassallo & Tseng, 2021). This approach offers significant advantages over univariate models by capturing the complex, interdependent nature of farmers' decisions (Getnet, 2023; Hiko *et al.*, 2020; Zheng *et al.*, 2020). The Count Data Model/ GLM correlation test was used to analyse the number of adaptation strategies implemented by each farmer. Before conducting the correlation analysis, the data were found to follow a normal distribution. The adoption of agricultural technologies, farm management techniques, and other discrete events have all been analysed using these models extensively in agricultural studies (Buyrukoğlu *et al.*, 2021). Specifically, the number of adaptation options that farmers employed was based on the Poisson regression model, with a focus on the

relationship between demographic, livelihood, and socio-economic variables. The specifications of the model are elaborated in Chapter 7 to avoid repetition.

The Household Food Insecurity Access Scale (HFIAS) was used to determine the food security status of the surveyed smallholder farmers, this aligns with previous studies conducted by Awodele and Olajide, (2020) & Roy *et al.*, (2022) who used the HFIAS to measure household food security in rural areas. This tool bases its results on food consumed in the previous four weeks by the respondent. This model was helpful. This model was more suitable for this study as it acknowledges the indexed nature of the various response variables. A more detailed method used to study the perceptions of climate change on the food security status of smallholder farmers is explained in Chapter 6, again to avoid duplication of information.

Table 3 - 1: Research Methods Table

Sub-Objectives	Data to be collected	Data collection techniques & tools	Analysis
<ul style="list-style-type: none"> To explore the effect of climate change on the food supply chain in Africa, with a focus on South Africa 	What has the relationship been between climate change and the food supply chain over the past 30 years?	<ul style="list-style-type: none"> PRISMA Guidelines JBI checklist Web of Science Scopus Google Scholar 	<ul style="list-style-type: none"> NVivo 12 Excel
<ul style="list-style-type: none"> To map the food supply chain in KwaZulu Natal by identifying key actors, analyzing the structure and assessing vulnerabilities within these systems. 	Information about the food supply chain in KwaZulu Natal, with regards to smallholder farmers and the agents.	<ul style="list-style-type: none"> Questionnaires Key Informative interviews 	<ul style="list-style-type: none"> Descriptive statistics frequencies thematic analysis SPSS
<ul style="list-style-type: none"> To evaluate the association of climate change perceptions on the income of smallholder vegetable farmers in KwaZulu Natal Province. 	<ul style="list-style-type: none"> Demographics Market information Income shares of the farmers and agents. Climate change information and perceptions 	<ul style="list-style-type: none"> Questionnaires 	<ul style="list-style-type: none"> Seemingly Unrelated Regression (SUR) model and Box-Cox regression model with a control function approach

			<ul style="list-style-type: none"> descriptive analysis
<ul style="list-style-type: none"> To explore the perceptions of climate change on food security by the smallholder farmers in KwaZulu Natal Province. 	<p>What are the smallholder farmer's views and observations about the impact of climate change on food security</p>	<ul style="list-style-type: none"> Questionnaires (5- or 7-point Likert scales) Focused group discussions. 	<ul style="list-style-type: none"> Frequencies and descriptive analysis Thematic and content analysis SPSS
<ul style="list-style-type: none"> To determine the factors influencing the choice and level of adaptation strategies among smallholder vegetable farmers in KwaZulu Natal Province. 	<ul style="list-style-type: none"> To identify the factors that influence smallholder farmers to use certain adaptation strategies. To identify the level of the adaptation strategies used by the farmers. 	<p>Questionnaires</p>	<ul style="list-style-type: none"> Multivariate probit model Count data model/ GLM Correlation descriptive analysis

3.7. Ethical consideration

Protecting research participants' privacy and confidentiality is an element of ethical consideration (Chakraborty & Bhattacharyya, 2019). This ensures that all responses recorded by the researcher are kept confidential. Given the sensitive nature of the information provided by participants, disclosing their identities could be harmful, making ethical considerations essential for protecting their anonymity (Bord & Channon, 2022). In this study, primary data was used, with permission granted by the Human and Social Sciences Research Ethics Committee (HSSREC) for data collection. In addition to securing ethical clearance (Appendix A) and ensuring informed consent, voluntary participation, and confidentiality, the study also implemented measures to address potential language and literacy barriers, which are particularly relevant in rural settings. Where necessary, questionnaires and consent forms were translated into isiZulu, the dominant local language. Furthermore, trained field assistants fluent in both English and isiZulu facilitated data collection, including during focus group discussions, to ensure participant understanding and comfort. For illiterate participants, oral

consent procedures were used, and questionnaires were administered verbally to uphold inclusivity and ethical rigor.

Additionally, a gatekeeper's letter from the Department of Agriculture authorized the researcher to conduct the study. All participants provided written informed consent, acknowledging their understanding of the study's objectives, methods, and their rights, including the option to withdraw at any time. Throughout the research, participant confidentiality and anonymity were strictly maintained, and data was securely stored with access restricted to the research team.

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CHAPTER 4

TO MAP THE FOOD SUPPLY CHAIN IN KWAZULU NATAL BY IDENTIFYING KEY ACTORS, ANALYZING THE STRUCTURE AND ASSESSING VULNERABILITIES WITHIN THESE SYSTEM.

Merishca Naicker¹, Denver Naidoo², Mjabuliseni Simon Ngidi³

1. African Centre for Food Security (ACFS), School of Agriculture Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg 3201, South Africa.
2. Department of Agricultural Extension and Rural Resources Management, School of Agriculture Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg 3201, South Africa.

* Correspondence: ngidim@ukzn.ac.za

Abstract: This study aimed to identify and analyse the challenges faced by smallholder farmers in the food supply chain in KwaZulu-Natal, South Africa, using a mixed-methods approach. Data were collected through surveys and interviews with 200 farmers and key stakeholders in the supply chain. The findings revealed that farming experience significantly influences productivity, yet farmers consistently underutilize their land. Most farmers operate outside formal supply networks, primarily selling at local and bulk markets through intermediaries, and many express dissatisfactions with the prices received. Transportation issues, including unreliability, lack of refrigeration, and adverse weather, were identified as significant obstacles. Climate change has exacerbated these challenges, leading to reduced food security, higher production costs, and frequent crop failures. Additionally, the sector's decline is linked to aging farmers, high production costs, and insufficient government support. Despite a brief post-COVID-19 increase in new farmers, many have struggled to sustain their businesses. The rise of informal traders has also altered market dynamics, driven by high unemployment. The study concludes that effective strategies to support smallholder farmers include government intervention, infrastructure development, financial support, and education on climate resilience.

Keywords: Food supply chain, supply chain mapping, smallholder farmers, climate change, KwaZulu-Natal

4.1. Introduction

The food supply chain in KwaZulu-Natal is a complex network that involves various stages and entities from production to consumption. Applying supply chain mapping techniques to this network can provide significant insights into the flow of goods, information, and finances, helping to identify inefficiencies and areas for improvement (Arumugam *et al.*, 2021). By visualizing the supply chain, stakeholders can pinpoint bottlenecks and implement targeted interventions to enhance the overall efficiency and sustainability of the food supply system.

KwaZulu-Natal is a region where a substantial portion of households rely on agriculture for both income and sustenance (Morales *et al.*, 2021). Smallholder farmers, such as those in the Ezemvelo Farmers' Organisation, often face numerous challenges in organic crop production and marketing within formal supply chains (Myeni *et al.*, 2019). Mapping these supply chains can reveal specific obstacles that smallholder farmers encounter, enabling the design of strategies to enhance their competitiveness and sustainability.

The region's susceptibility to food insecurity further emphasizes the need for effective food supply chain management. Studies on rural South Africa, including KwaZulu-Natal, highlight the critical importance of prioritizing food policy agendas to address these vulnerabilities (Chikozho & Makore, 2020; Mthethwa & Wale, 2021). By identifying vulnerable areas and populations through supply chain mapping, targeted interventions can be developed to improve food security and access for those most at risk.

Additionally, the exploration of short food supply chains (SFSCs) offers a promising avenue for enhancing sustainability. SFSCs, characterized by their localized and efficient nature, can be more sustainable compared to conventional mass food delivery systems (Malak-Rawlikowska *et al.*, 2019). Mapping out existing SFSCs and evaluating their sustainability metrics can provide valuable insights into best practices that could be scaled up across the region.

Understanding and optimizing the food supply chain in KwaZulu-Natal is essential for improving food security, promoting sustainability, and enhancing the livelihoods of smallholder farmers. Smallholder farmers in KwaZulu Natal face growing challenges from climate change and weak food supply chain systems. They struggle with poor infrastructure, limited market access, and minimal institutional support, which threatens their livelihoods and regional food security. This highlights the urgent need to assess and strengthen the province's food supply chain. This study aims to utilize supply chain mapping techniques to gain a

comprehensive understanding of the food supply chain in the region. By mapping out the various stages and entities involved, we can identify inefficiencies, bottlenecks, and areas for improvement.

Previous studies have indicated several inadequacies and constraints in the comprehension and administration of food supply networks within the area. According to Davis *et al.* (2020), strengthening the food supply chain's resilience to environmental shocks is crucial and implies the need for more effective plans in the event of disruptions. Akinola *et al.* (2020) emphasized the need for a deeper comprehension of regional food systems by pointing out a knowledge gap about native food crops in Africa and the discrepancy between prospective varieties for consumption and the actual kinds being consumed.

Additionally, Maziya *et al.* (2024) highlighted the need to take social capital into account when designing interventions for food security and the need to comprehend the contextual elements that affect food insecurity. Furthermore, Chinyerere *et al.* (2021) underlined the connection between food and nutrition insecurity in KwaZulu-Natal's rural communities, emphasizing the necessity of bridging the gap between agricultural and human nutrition to solve these issues. All these studies highlight how complex the food supply chains are, how significant local contexts are, and how comprehensive strategies are required to improve food security and sustainability.

The proposed study holds relevance as it has the potential to address important gaps in knowledge regarding KwaZulu-Natal's food supply chain. The study attempts to give a thorough comprehension of the dynamics, players, and procedures involved in the food supply chain in the region by using supply chain mapping methodologies. In the end, our research may improve food and nutrition security outcomes for nearby populations by strengthening the food supply chain's resilience, sustainability, and efficiency.

Thus, this study's objectives are to map the KwaZulu-Natal food supply chain in its entirety, identify important players, procedures, and problems, and provide solutions to improve the food supply chain's sustainability and resilience.

4.1.1. Theoretical underpinnings

The theoretical framework underpinning this study is based on Value Chain Analysis (VCA), a method rooted in systems thinking and economic theory, which provides a structured approach to understanding the configuration, performance, and vulnerabilities of production-to-consumption systems (Kaplinsky and Morris, 2001). Originating from Porter's (1985)

conceptualisation of competitive advantage, VCA enables the disaggregation of a product's journey into sequential activities, identifying actors, their roles, and the value they add or lose at each stage. This framework is instrumental in mapping the food supply chain in KwaZulu Natal, particularly in the context of smallholder vegetable production, where actors are often informal, geographically dispersed, and vulnerable to environmental and market shocks.

VCA is applied in this study to achieve three interrelated goals. First, it facilitates the identification of key actors within the supply chain, including input suppliers, smallholder farmers, aggregators, transporters, market agents, processors, and consumers. These actors often operate under uneven power dynamics, which can affect their bargaining positions and access to resources and markets (Bolwig *et al.*, 2010). Second, VCA allows for the structural analysis of the chain, uncovering both vertical and horizontal linkages and revealing the governance mechanisms that influence how benefits and risks are distributed. This is particularly relevant in KwaZulu Natal, where informal marketing systems and limited infrastructure may exacerbate inequality and inefficiencies in the chain (Donovan *et al.*, 2015).

Third, the framework is essential for assessing vulnerabilities within the food supply chain. By identifying critical control points and bottlenecks, such as climate-sensitive stages of production, transportation constraints, or poor post-harvest handling, VCA supports the diagnosis of systemic weaknesses. These weaknesses are often magnified for smallholder farmers who lack access to climate information, storage facilities, or resilient infrastructure (FAO, 2020). Integrating VCA into this study provides a comprehensive understanding of how environmental, institutional, and socio-economic factors intersect across the supply chain, making it possible to propose context-specific adaptation strategies for improved resilience and food security.

Thus, value chain analysis not only aligns theoretically with the study objective but also serves as a practical lens through which to examine the interconnectedness and fragility of rural food systems. It bridges micro-level production realities with macro-level supply chain dynamics, enabling a holistic assessment of food system resilience in the face of climate change.

4.2. Material and methods

4.2.1. Description of the Study

The research was conducted in KwaZulu-Natal, a South African province renowned for its diverse landscapes, rich cultural heritage, and historical sites. The province's economy is sustained by agriculture, manufacturing, tourism, and mining (Kwazulu-Natal Municipalities, 2024). The climate varies across the region, fostering agricultural diversity. The

coastal belt is a significant sugarcane-growing area, with numerous sugar mills contributing to the national output (Kwazulu-Natal Municipalities,2024). The province also produces fruits, vegetables, beef, poultry, and forestry plantations, as well as speciality crops such as tea, coffee, and nuts (Elgorashi, 2019).

The surveyed respondents comprised smallholder vegetable farmers in the province, with all 11 districts participating in the survey, as seen in Figure 4-1 below. The primary crops planted by these smallholder farmers include spinach, cabbage, dry beans, and green beans (STATS SA, 2022). These farmers face numerous challenges, exacerbated by climate change, which impact the quality, quantity, and shelf life of their produce, thereby affecting the supply chain (Maziya,2024). Water management is essential for agricultural productivity, and climate change poses challenges in this regard (Leonard, 2022). Agriculture plays a vital role in the livelihoods of rural communities in KwaZulu-Natal, providing employment and food for their households (Ncoyini-Manciya & Savage, 2022). This study aims to analyze the food supply chain in KwaZulu-Natal using supply chain mapping, focusing on smallholder vegetable farmers.



Figure 4- 1: Map of KwaZulu-Natal and its districts (Accessed: 08/07/2024)

<https://www.researchgate.net/publication/336959309/figure/fig1/AS:864432544571411@1583108187597/Map-of-KwaZulu-Natal-Province-Municipalities-Wikipedia-2016.png>

4.2.2. Research design

This study employed a mixed-methods approach to comprehensively explore the challenges faced by smallholder vegetable farmers within the food supply chain in KwaZulu-Natal. Conducted over four months from December 2023 to March 2024, the research design integrated both quantitative and qualitative methodologies to provide a robust analysis of the supply chain dynamics.

The quantitative component of the study involved administering a structured questionnaire to a purposively selected sample of 200 smallholder farmers. These farmers were chosen based on their active engagement in vegetable farming and their registration with local agricultural organizations. The questionnaire was designed to capture essential data on demographics, farming practices, supply chain activities, and the specific challenges faced within the supply chain. By including both closed and open-ended questions, the survey facilitated statistical analysis while also allowing respondents to provide detailed insights into their experiences (Creswell & Creswell, 2021).

In parallel, the qualitative component comprised key informant interviews with 22 market agents and middlemen, who were selected for their critical roles in the food supply chain. These semi-structured interviews were conducted in person at locations convenient for the participants. The interview guide was crafted to delve into the roles and processes within the supply chain, the challenges encountered, and potential areas for improvement. All interviews were audio-recorded with participant consent and transcribed verbatim for rigorous thematic analysis (Braun & Clarke, 2019).

The integration of quantitative and qualitative data allowed for a comprehensive analysis, enhancing the depth and reliability of the findings. Quantitative data were analyzed using descriptive statistics to identify key patterns and relationships, while qualitative data were analyzed thematically to uncover deeper insights into the supply chain challenges. This mixed-methods approach enabled the triangulation of data, ensuring a well-rounded understanding of the complexities within the food supply chain (Schoonenboom, 2020).

4.2.3. Study population and sampling design

This study employed a purposive sampling technique to select participants who are directly involved in the food supply chain. This technique enables researchers to focus on people who have the traits or life experiences that are most pertinent to the study (Strattos, 2024). The sample population for the questionnaire survey comprised smallholder vegetable farmers,

while key informant interviews were conducted with market agents and middlemen based on their roles and experience in the supply chain. The sampling frame included smallholder vegetable farmers registered with local agricultural organizations and market agents operating within KwaZulu-Natal, this provided a comprehensive overview of the agricultural landscape and potential participants (Suryono *et al.*, 2022). Lists of registered farmers and market agents were obtained from local agricultural offices and market directories to ensure a comprehensive representation (Chen *et al.*, 2021).

The study was conducted over four months, from December 2023 to March 2024. The target population consisted of 200 smallholder farmers in KwaZulu-Natal who are actively engaged in vegetable farming. In addition, 22 key informant interviews were conducted with market agents and middlemen who play a critical role in the food supply chain (Haji *et al.*, 2020).

The questionnaire was meticulously designed to capture detailed information about the food supply chain, encompassing demographics, farming practices, supply chain activities, challenges faced, and perceptions of market agents. The questionnaire included both closed-ended and open-ended questions, allowing for the collection of quantitative data and qualitative insights (Raffington, 2024).

Key informant interviews were conducted in person, using a semi-structured interview guide tailored to explore the roles of market agents, supply chain processes, challenges encountered, and potential improvements (Vrij & Leal, 2021). Interviews were conducted at locations convenient for the participants, and all sessions were audio-recorded with participant consent. The recordings were then transcribed verbatim for thorough analysis (McNamara, 2024).

The mapping process drew on qualitative interviews with key stakeholders, including smallholder farmers, local market agents, extension officers, and supply chain intermediaries, to gain a grounded understanding of the food supply chain. These interviews enabled the identification and validation of core stages such as production (including input sourcing and on-farm practices), aggregation (grouping and storage of produce), and marketing (distribution to local and formal markets). Respondents provided context-specific insights into how these stages function in practice, the actors involved, and the challenges encountered at each level. This participatory approach ensured that the mapped supply chain comprehensively reflected the lived experiences and operational realities within the KwaZulu-Natal region.

4.2.4. Data analysis

The study employed a mixed-methods approach to analyze data and gain a comprehensive understanding of food supply chain challenges among smallholder vegetable farmers in KwaZulu-Natal. Quantitative data from structured questionnaires were analyzed using descriptive statistics and cross-tabulations in SPSS to identify patterns in farming practices and supply chain activities. Qualitative data from key informant interviews were analyzed thematically using NVivo, revealing insights into market roles, challenges, and proposed improvements. The qualitative data derived from the key informant interviews were analyzed using thematic analysis, a method suitable for identifying, analyzing, and reporting patterns within qualitative data (Braun & Clarke, 2019). Triangulation of both data types strengthened the study's validity and provided a richer, more integrated view of supply chain dynamics and farmer experiences. This mixed-methods approach enabled the validation of results by cross-verifying the quantitative patterns with qualitative insights, thereby enhancing the overall reliability and validity of the study's conclusions (Creswell & Creswell, 2021).

4.2.5. Ethical Considerations

The study received ethical approval from the Human and Social Sciences Research Ethics Committee (HSSREC). Informed consent was obtained from all participants, who were informed about the study's purpose, their rights, and the confidentiality of their responses. Participants were assured that their participation was voluntary and that they could withdraw at any time without penalty. A gatekeeper's letter was obtained from the Department of Agriculture, to access the information of the smallholder farmers in KwaZulu-Natal.

4.3. Results and discussion

4.3.1. Socioeconomics and distribution of farm characteristics

Table 4-1 presents the demographic profile of the 200 surveyed smallholder farmers, offering insights into how age, gender, education level, and marital status potentially influence their mode of participation in the food supply chain.

The respondent sample comprised 65% males and (35%) females. This gender disparity reflects broader structural inequalities in land access, capital, and decision-making power in rural agricultural settings. Male farmers, who often control larger plots and have greater access to resources and transportation, are more likely to engage in direct selling to markets or through intermediaries (Mthethwa & Wale, 2021). Conversely, female farmers, who may face mobility and resource constraints, are more reliant on local informal networks or community-

based cooperatives, where they benefit from shared support and collective bargaining. This difference highlights the need for gender-sensitive supply chain interventions that expand women's market access and entrepreneurial capacity.

The age distribution shows a significant number of older farmers, with (47.5%) aged 54 and above. Older farmers may be less inclined to adopt innovative supply chain strategies, such as digital platforms or new marketing channels, due to technological illiteracy or risk aversion. This age group tends to rely more on traditional selling methods or trusted intermediaries. Younger farmers (aged 26–39), who account for (22.5%) of respondents, are generally more open to experimentation and may participate in direct marketing, agro-processing, or niche markets. This aligns with findings by Liu *et al.* (2019), who argue that younger farmers are more adaptive, technically efficient, and innovation-oriented, qualities critical for resilient supply chain development.

Education is a crucial determinant of how farmers engage with the supply chain. Over half of the respondents (50.5%) have secondary education, and (18.5%) possess tertiary qualifications. These farmers are better equipped to interpret market signals, manage record-keeping, and understand regulations, making them more likely to engage in value-added activities, contract farming, or cooperative-based marketing. In contrast, farmers with no formal education (6%) or only primary schooling (25%) are more likely to rely on middlemen, due to limited market literacy and poor access to price information. Education also influences a farmer's likelihood of engaging with extension services and adopting post-harvest handling techniques, which are critical for meeting quality standards in formal markets (Malak-Rawlikowska *et al.*, 2019).

The data show that (52.5%) of the farmers are married. Married farmers often benefit from additional household labor and financial stability, which can facilitate participation in cooperatives and bulk marketing strategies. In contrast, single or widowed farmers may lack the support systems necessary for engaging in labor-intensive or large-scale marketing channels, often resulting in subsistence-level production or reliance on local informal sales. Moreover, widowed (12%) and divorced (9.5%) respondents, often women, may face social exclusion or reduced access to land and capital, further constraining their participation in lucrative supply chain segments.

Table 4- 1: Demographics of the surveyed respondents of smallholder farmers in KwaZulu-Natal.

Variable		Frequency (n=200)	Percentage (%)
Gender	Male	130	65
	Female	70	35
Marital status	Single	52	26
	Married	105	52,5
	Divorced	19	9,5
	Widowed	24	12
Education level	No Formal Education	12	6
	Primary	50	25
	Secondary	101	50,5
	Tertiary & above	37	18,5
Age	26-39	45	22,5
	40-53	60	30
	54-67	56	28
	68-81	34	17
	82-88	5	2,5

The study's results indicate a significant preference for vegetable farming, with 100% of respondents engaged in this activity as seen in Figure 4-2 below. This dominance suggests optimal environmental conditions and a high market demand for vegetables in KwaZulu-Natal. Such trends align with the findings of Van Leeuwen *et al.* (2024), who observed similar patterns in regions with favourable agro-climatic conditions and strong market preferences. Poultry farming follows at 15%, reflecting its importance in providing protein-rich food essential for nutrition security. The engagement in poultry farming, while lower than vegetable farming, underscores its role in the food supply chain.

Grain and livestock farming engage 9.5% and 8% of respondents, respectively. These activities, though less prevalent, are crucial for food diversity and economic stability. Grains serve as staple foods, while livestock farming supports livelihoods through meat and dairy production, contributing to both food and economic security. Pulses, fish farming, and fruit production involve 3%, 1.5%, and 1% of respondents, respectively. Despite their lower engagement, these activities are important for dietary diversity and can enhance food system resilience by providing varied sources of nutrition and income.

The predominance of vegetable farming highlights the influence of economic and environmental factors. Factors such as market demand, shorter production cycles, and favourable growing conditions likely drive this trend. However, the presence of diverse agricultural activities, though less common, is essential for the resilience and sustainability of the food system (Gordhan & Nthabana, 2022). Policymakers should leverage this data to

support the development of less common agricultural practices. Encouraging diversity in food production can mitigate risks associated with environmental changes and market fluctuations. For instance, promoting grain and livestock farming can provide a buffer against crop failures or price drops in the vegetable market. Additionally, investments in pulses, fish farming, and fruit production can improve nutritional outcomes and economic opportunities for farmers (Maziya *et al.*, 2024).

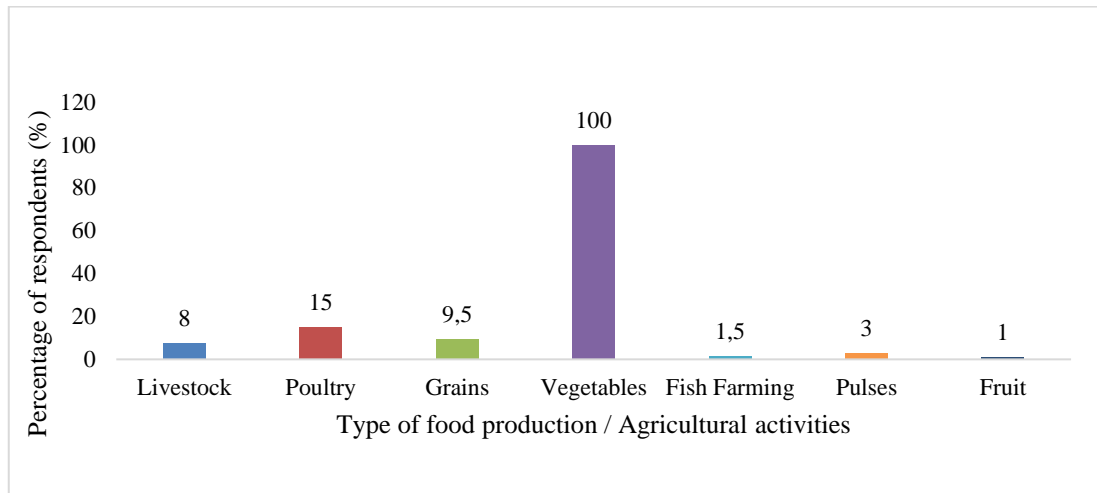


Figure 4- 2: Percentage of Respondents Involved in Various Types of Food Production.

The data on land ownership and utilization provide essential insights into the food supply chain in KwaZulu-Natal. Figure 4-3 illustrates that the size of land owned by smallholder farmers ranges from 1 to 65 hectares, with the majority (13%) owning 10 hectares. Figure 4-4 shows that the size of land used for agricultural practices ranges from 1 to 30 hectares, with the majority (20.5%) using 5 hectares for agricultural production.

The size of land owned and utilized for agriculture plays a significant role in shaping productivity outcomes and overall agricultural sustainability (Zhang & Zheng, 2020). Smallholder farmers with limited land face challenges in achieving economies of scale, which can affect their productivity and efficiency. Larger farms may benefit from more efficient resource allocation, but the actual land used for agricultural production is often constrained by external factors such as capital availability and labour forces.

These findings are critical for mapping the KwaZulu-Natal food supply chain as they highlight the variability in land ownership and usage among smallholder farmers. This variability affects production efficiency and resource allocation, which are key components of the food supply

chain (Chikozho & Makore, 2020). The interaction of farm size, land tenure systems, environmental conditions, and regional characteristics significantly influences the efficiency and resilience of the agricultural sector (Bhandari *et al.*, 2021).

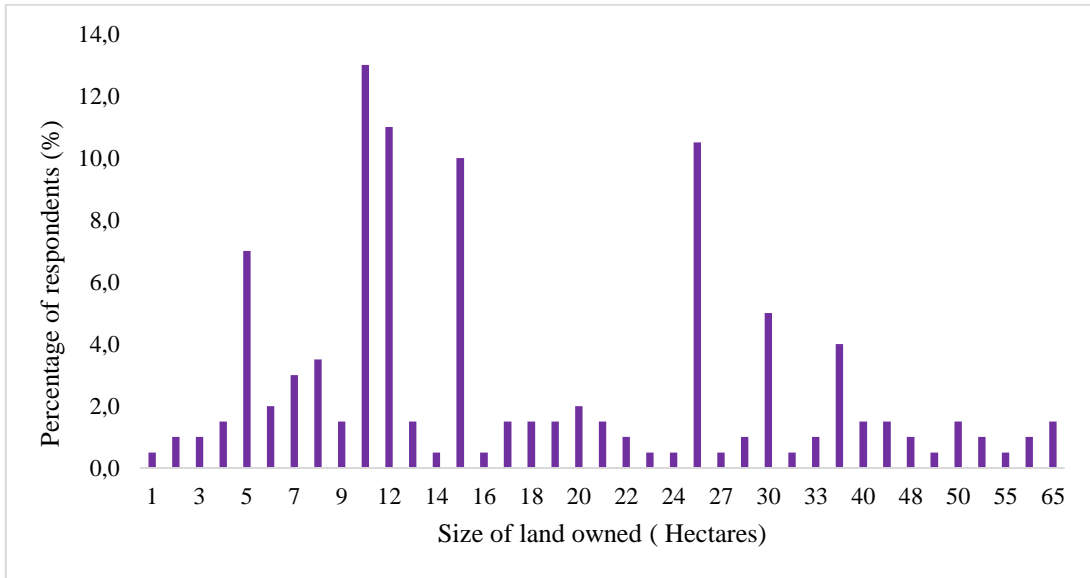


Figure 4- 3: Size of land owned by respondents.

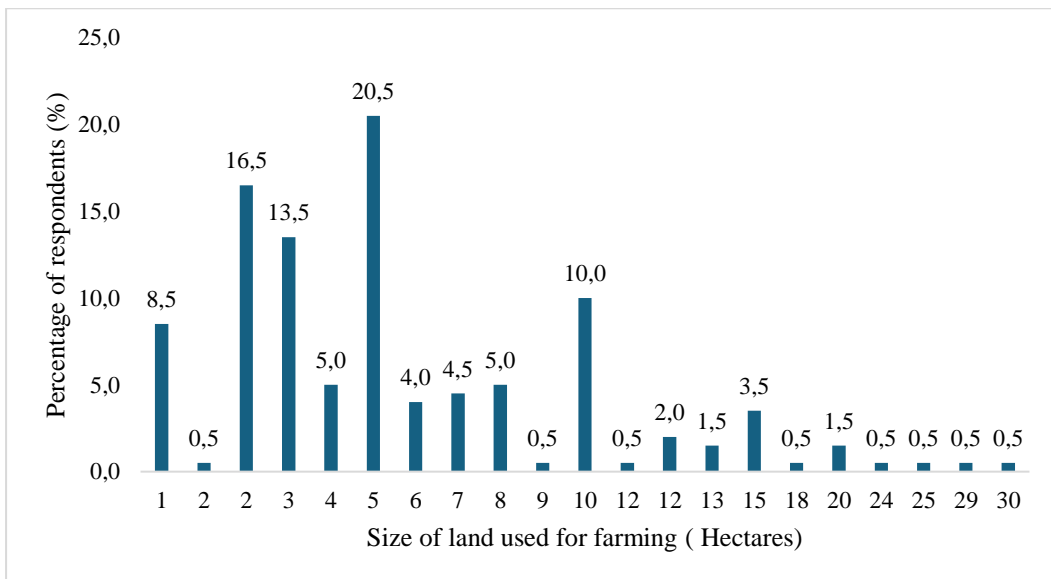


Figure 4- 4: Size of land used for agricultural production.

4.3.2. Supply chain dynamics amongst the surveyed smallholder farmers.

The food supply chain in South Africa is a complex system involving numerous stakeholders, including farmers, processors, wholesalers, retailers, and consumers (Mishra *et al.*, 2021). The

data in Table 4-2 shows that a minority of respondents are involved in formal or informal food supply chain networks or associations. These associations include cooperatives (9.5%), market associations (17%), and other relevant organizations such as farmers associations and local farmers support groups (11.5%). The limited involvement in supply chain networks and associations indicates potential challenges in the integration and collaboration among stakeholders within the KwaZulu-Natal food supply chain. Participation in such networks can provide farmers with better access to markets, shared resources, and collective bargaining power, which are essential for enhancing their productivity and market reach. The lack of engagement in these networks could result in inefficiencies and reduced resilience within the food supply chain.

Table 4- 2: Types of formal or informal food supply chain networks of associations participants belong to.

Involved in any formal or informal food supply chain networks or associations.	Percentage of Participants (%)
Yes, I am part of a cooperative	9,5
Yes, I am part of a market association	17
Yes, I am part of other relevant organisations	11,5
No, I am not involved in any such networks or associations	62

4.3.3. Sale dynamics of smallholder farmers in KwaZulu-Natal

Nwafor (2020) underscores the importance of understanding sales dynamics and available market outlets for smallholders in different regions. The results of this study indicate that the majority of smallholder farmers' primary point of sale is the local markets (45.5%), followed by the bulk market (31%) and local stores (18%), as shown in Figure 4-5.

The dominance of local markets as the primary point of sale highlights the critical role these markets play in the food supply chain. Local markets provide accessible and immediate sales opportunities for smallholder farmers, ensuring a steady income and reducing post-harvest losses (Oriekhoe, 2024). The bulk market's significant share (31%) reflects its importance in aggregating produce for larger-scale distribution, which can enhance market reach and stability for farmers. The role of local stores (18%) indicates the potential for smallholder farmers to establish stable and consistent sales channels, albeit on a smaller scale. These findings are integral to mapping the KwaZulu-Natal food supply chain, as they reveal the primary sales channels and market dynamics that influence the flow of goods from producers to consumers. Understanding these dynamics is essential for identifying key players, procedures, and problems within the supply chain (Singh, 2024).

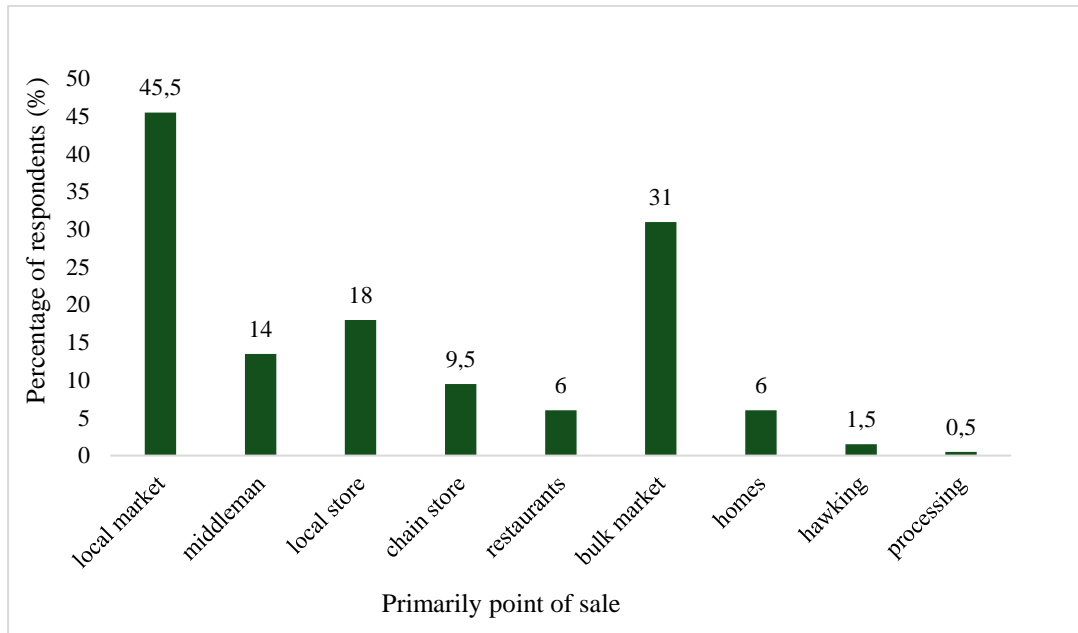


Figure 4- 5: Primary point of sale for respondents.

Intermediaries play an essential role in the supply chain by providing market access and marketing services for urban fresh fruits and vegetables in South Africa (Yi *et al.*, 2021). Their functions include promoting the flow of information, creating market opportunities, and facilitating the overall supply chain process (Agbiz Research,2022). Intermediaries play a key role but contribute to dissatisfaction with prices due to information asymmetry. Climate change further exacerbates supply chain weaknesses by reducing produce quality and availability, which limits sales and undermines resilience. Improving integration into formal networks, access to market information, and awareness of policies could help strengthen market participation and build climate resilience for smallholder farmers (Yi *et al.*, 2021).

According to the data presented in Figure 4-6, the majority of intermediaries (41.5%) were market agents, followed by middlemen (33.5%), with hawkers representing the smallest proportion (1%). The majority of smallholder farmers in KwaZulu-Natal operate outside formal supply chain networks, relying heavily on informal channels such as local markets and intermediaries. While these channels offer accessible sales options, they limit price negotiation, transparency, and market reach. Low involvement in cooperatives or associations weakens farmers' bargaining power and reduces access to shared resources. This structure also hampers food traceability and compliance with safety standards, especially given that few farmers are aware of relevant regulations (Agbiz Research,2022).

The presence of intermediaries, however, introduces a lack of transparency within the agri-food supply chain, posing a significant challenge in South Africa. This underscores the need

for a deeper understanding of the roles these intermediaries play (Yi *et al.*, 2021). Various marketing intermediaries are involved in the distribution of agricultural products from producers to consumers, a common characteristic of South Africa's supply chains (Banga & Balchin, 2022). Banga and Balchin (2022) further highlight that intermediaries can facilitate direct connections between producers and consumers, a dynamic that is critical to comprehending the intermediary landscape in South Africa.

Key informant interviews revealed that recent climatic events have significantly impacted the sales of produce by smallholder farmers in South Africa. According to Omotoso (2023), Smallholder farmers are adversely impacted by climate change and need to adopt adaptation strategies to mitigate these impacts. These impacts manifest primarily through reduced availability and compromised quality of produce, leading to decreased sales and financial strain on farmers. Adverse weather conditions have directly contributed to the diminished availability of produce, while climate-induced quality deterioration results in slower sales. The increasing risks that smallholder farmers confront as a result of climate shocks, underlining the susceptibility of smallholder agriculture and food security to climate change in Southern Africa (Mutengwa *et al.*, 2023). Conversely, the limited availability of high-quality produce commands better prices and sales, though such instances are rare. The unpredictable weather patterns have disrupted the availability of seasonal vegetables and fruits, leading to faster wilting and reduced shelf life, which negatively affects marketability (Phophi *et al.*, 2020). As a result, farmers are often compelled to sell lower-quality produce at reduced prices or risk wastage. Despite higher prices driven by increased demand and decreased supply, the compromised quality of produce and escalating costs of inputs such as fertilizers further complicate market dynamics. Elevated prices have not necessarily translated into improved sales, as consumers are often unwilling to purchase at inflated prices and may seek alternatives. For smallholder farmers, the combination of weather-related difficulties, reduced product quality, rising prices, and rising input costs produces a complex and difficult market environment (Muthelo *et al.*, 2019). This challenging market environment highlights the financial and operational difficulties that smallholder farmers face, compounded by changing consumer behaviours and the broader impacts of climate change (Thompson & Chauke, 2021).

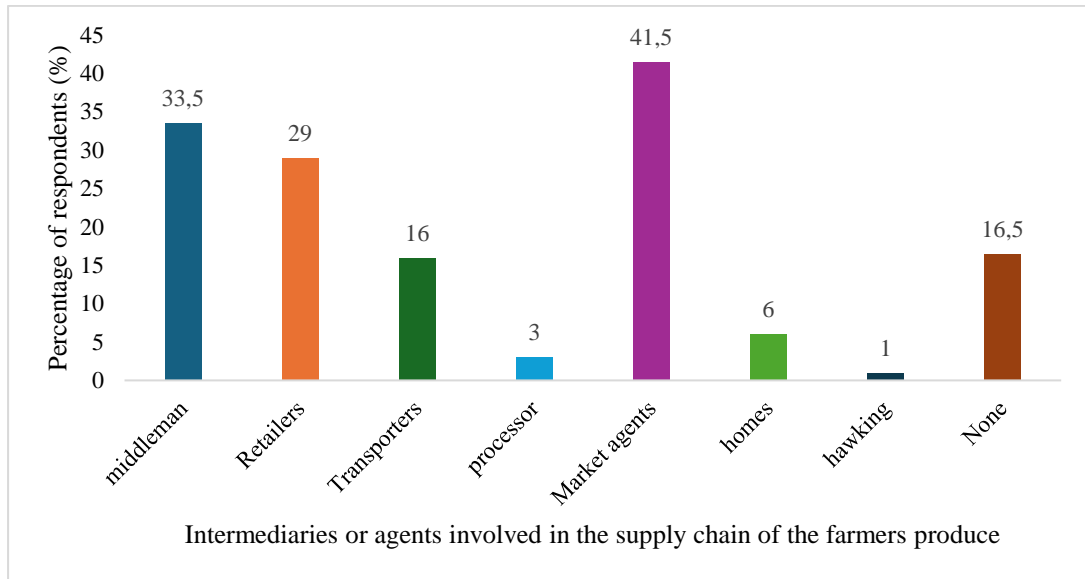


Figure 4- 6: Intermediaries or agents involved in the supply chain of the farmers' produce.

Smallholder farmers in South Africa face significant challenges related to their satisfaction with the prices of their produce. These challenges arise from a range of factors, including market failures, limited access to market information, and barriers that prevent them from fully exploiting market opportunities (Hlatshwayo *et al.*, 2021; Zondi *et al.*, 2022; Kalauba *et al.*, 2023). A major contributor to their disadvantage is the lack of knowledge about prevailing market prices for their commodities, which impairs their ability to negotiate effectively (Mwadzingeni *et al.*, 2020; Nyawo & Mubangizi, 2021).

As indicated in Table 4-3, the majority of participants (30%) expressed dissatisfaction with the prices they received for their produce, while only a minority (6.5%) reported being very satisfied. The dissatisfaction with produce prices is further exacerbated by the fact that smallholder farmers often produce only a small surplus, which is difficult to market effectively, leading to challenges in attracting buyers and accessing international markets (Mdoda *et al.*, 2022). Despite these challenges, 72% of respondents felt that the existing food supply chain adequately serves their needs and interests. However, only 13% of respondents were aware of the policies or regulations governing the food supply chain, such as those related to food safety and quality standards, which directly affect their operations.

Addressing these challenges and improving smallholder farmers' satisfaction with produce prices requires targeted interventions to enhance market access, provide timely market information, promote modern agricultural technologies, and strengthen linkages with buyers and markets (Shikwambana *et al.*, 2022). Strategies such as digital trading platforms, public extension services, and joint venture schemes could play a crucial role in improving market

participation and ensuring fair pricing for smallholder farmers (Hlatshwayo *et al.*, 2021). By addressing these issues and expanding market opportunities, smallholder farmers in South Africa could improve their livelihoods, increase profitability, and make a more substantial contribution to the agricultural sector.

Key informant interviews highlighted that recent climatic events have significantly affected the pricing of produce from smallholder farmers in South Africa, mainly through their impact on produce quality and availability. Weather-related issues, including floods, hail, extreme heat, and excessive rain, have devastated crops and seedlings, leading to severe shortages. These adverse conditions have also caused produce to rot or sustain damage, further diminishing the quality of available goods. According to, Yegbemey *et al.* (2021), smallholder farmers struggle to meet the demand of the market due to weather induced challenges. Natural disasters such as floods and fires have exacerbated these problems, resulting in even more significant reductions in both produce quality and availability. This scarcity has driven prices up, with high demand and limited supply causing prices to surge. However, the economic pressure is compounded by the loss of market value for weather-damaged stock, undermining farmers' profitability despite the potential for high prices (Shumba, 2022).

Furthermore, the lack of appropriate mechanization, labour shortages, and water scarcity intensify the challenges smallholder farmers face (Sayed *et al.*, 2022; Ramatshekgisa, 2024). These factors limit their ability to cope with the impacts of climate change and seasonal variations. The reliance on rain-fed agriculture increases production uncertainty due to climate variability, making it difficult for smallholder farmers to plan and sustain their agricultural activities (Tesfahuney & Mbeletshie, 2021). Traders, including hawkers and street vendors, are also affected by these conditions, as the scarcity and high prices of produce make it challenging to maintain their businesses. The overall economic impact is evident in increased costs for traders and decreased demand for crops, which collectively contribute to the soaring prices and difficult market conditions faced by both farmers and traders. The issue of satisfaction with produce prices is further complicated by the small surplus produced by smallholder farmers, which hinders effective marketing and access to broader markets (Mdoda *et al.*, 2022).

Table 4- 3: Satisfaction with prices received for produce.

Satisfaction with prices received for produce	Percentage of Participants (%)
Very satisfied	6,5
Satisfied	27
Neutral	22,5
Dissatisfied	30
Very dissatisfied	14

4.3.4. Challenges experienced by smallholder farmers.

Smallholder farmers in South Africa face a myriad of challenges that hinder their agricultural productivity and overall well-being. These challenges are not only diverse but also deeply entrenched in the socio-economic and environmental landscape of the country (Adomako *et al.*, 2021). The findings from this study, which sought to map the KwaZulu-Natal food supply chain, identify key players, procedures, and problems, and provide solutions for sustainability and resilience, are consistent with the broader challenges identified in other regions of South Africa.

The limited access to markets and essential resources emerged as a critical barrier for smallholder farmers in KwaZulu-Natal, mirroring similar findings in other provinces. This study found that farmers' ability to participate in the food supply chain is often constrained by inadequate infrastructure, including poor road networks and a lack of storage facilities. The difficulty in accessing reliable and affordable transport services was particularly evident, with a significant portion of respondents (15.5%) citing unreliable transport, and others highlighting high fuel costs (7.5%) and lack of refrigeration in vehicles (1%) as major obstacles (Figure 4-7). Smallholder farmers in KwaZulu Natal use carpooling as an adaptive strategy to overcome transport challenges and ensure their produce reaches local markets, as mentioned by the surveyed farmers. These farmers incur additional transportation costs, contributing approximately R100 per trip through carpooling arrangements. In some instances, they entrust their produce to fellow farmers for delivery to the market, paying a fee for this service. This practice reflects a significant level of trust and cooperation among the farming community. By sharing vehicles, they reduce costs, minimize post-harvest losses, and maintain market access, highlighting both their resilience and the need for improved infrastructure and support systems.

These transport-related challenges align with findings by Khoza *et al.* (2019) in Gauteng province, where socio-economic factors significantly influenced smallholder farmers' decisions to participate in the agro-processing industry. The inability to effectively transport

produce to markets not only limits income opportunities but also exacerbates post-harvest losses, further undermining the sustainability of smallholder farming operations.

Environmental factors such as drought and climate change continue to pose substantial threats to agricultural productivity in KwaZulu-Natal. The region's farmers are increasingly facing unpredictable weather patterns, which complicate planting schedules and affect crop yields. These challenges are compounded by limited access to water resources and inadequate irrigation infrastructure, making it difficult for farmers to mitigate the impacts of prolonged dry spells (Chikozho & Makore, 2020).

The barriers affecting sustainable agricultural productivity in the eastern Free State, as discussed by Myeni *et al.* (2019), resonate with the findings from KwaZulu-Natal. The struggle to achieve long-term viability in farming practices is intensified by the need to adapt to changing climatic conditions without adequate support systems or access to adaptive technologies.

The socio-economic dynamics within the KwaZulu-Natal food supply chain reveal a complex interplay of factors that either facilitate or hinder smallholder farmers' integration into sustainable value chains. Many farmers remain on the periphery of formal value chains due to factors such as limited bargaining power, lack of access to finance, and inadequate knowledge of market demands and standards (Damdam *et al.*, 2023).

This marginalization is reflective of broader trends observed across South Africa, where smallholder farmers struggle to transition from subsistence to commercial farming. The need for targeted interventions that address these socio-economic barriers is critical for improving the resilience of the food supply chain. By fostering stronger linkages between smallholder farmers and other stakeholders in the supply chain, such as agro-processors, wholesalers, and retailers, there is potential to enhance market access, improve income stability, and contribute to the overall sustainability of the agricultural sector (Chikowo *et al.*, 2020).

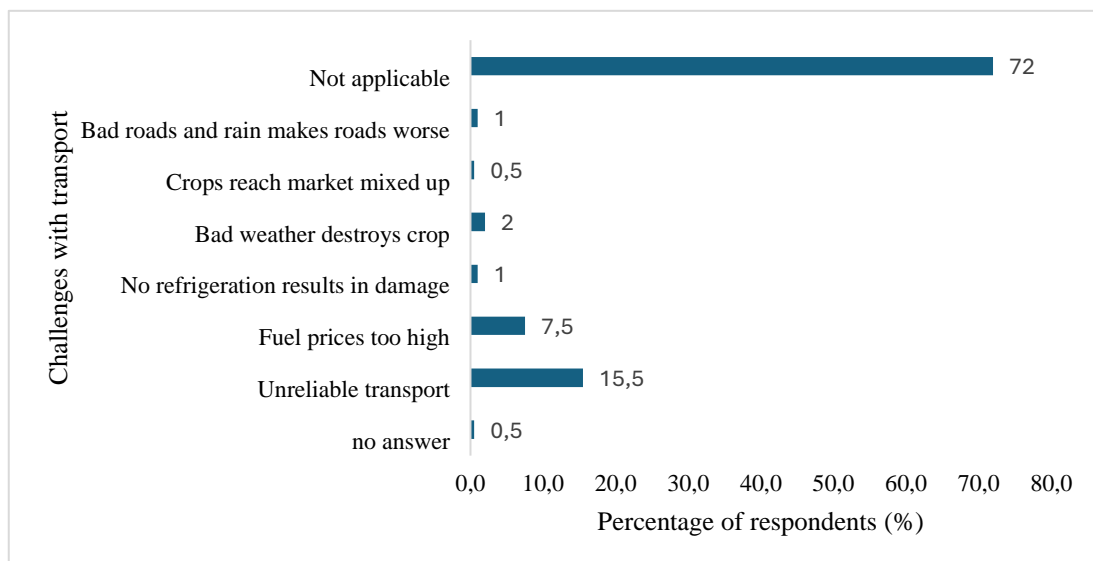


Figure 4- 7: Challenges experienced with transportation.

Smallholder farmers in South Africa are increasingly vulnerable to the effects of climate variability and extreme weather events, which pose significant challenges to their agricultural practices and livelihoods. Seasonal changes, particularly those driven by climate change, have exacerbated the vulnerability of these farmers, who are largely dependent on rain-fed agriculture. Prolonged droughts, erratic weather patterns, and the broader impacts of climate change have been identified as critical factors contributing to this vulnerability (Maltou & Bahta, 2019; Olabanji *et al.*, 2021; Maziya *et al.*, 2024).

A substantial proportion of surveyed respondents (40%) reported experiencing difficulties related to seasonal changes, which adversely affect their farming operations. In response to these challenges, farmers have adopted various strategies to ensure the quality and freshness of their produce. Quick delivery (32%) and proper packaging (19%) were among the most commonly employed methods, as illustrated in Table 4-4.

Key informant interviews revealed that over the past decade, South Africa's smallholder farmers have experienced a significant decline in produce production due to factors such as climate change, rising production costs, criminal activities, social unrest, outdated farming practices, and the perception of farming as unprofitable. Changes in labour laws and employment regulations have further strained farming operations. The COVID-19 pandemic has also contributed to farm closures and reduced agricultural output. The shelf life of produce has decreased due to extreme temperatures, unpredictable weather, and load shedding, while inadequate cold storage facilities exacerbate this issue. These challenges cause a decline in the farmer's profits and productivity (Chikowo *et al.*, 2020).

Farming practices also influence produce quality and shelf life. The use of cheaper seedlings and chemicals often results in inferior quality produce that does not last as long. Additionally, adverse climate conditions force farmers to harvest early, negatively impacting the shelf life of their crops. While some respondents did not notice changes in shelf life or could not comment due to specific circumstances, the prevailing issues of climate change, power outages, and poor cold chain management remain the primary factors contributing to the reduced shelf life of produce. Smallholder farmers can increase the marketability and durability of their products by using proper methods and cutting-edge technologies, which will ultimately increase their competitiveness and sustainability in the market (Fagbemi Olu *et al.*, 2022).

To manage food waste, smallholder farmers adopt various methods when produce cannot be sold. A common practice is repurposing unsellable produce as compost or donating it to pig farmers for animal feed. Kamoga & Charles (2022) highlights that composting is an effective way for farmers to reduce waste. Edible produce that cannot be sold is often donated to non-profit organizations, charities, or local communities. Some farmers opt to reduce the price of wilting produce to encourage quick sales. When produce is no longer viable, it must be disposed of according to health regulations, leading to the dumping of condemned or unsellable items. Doan & Tuan (2021) emphasized how waste must be recycled to benefit farmers, and that just disposing of waste is not viable for farmers. A few respondents reported no waste management issues, as they operate strictly on an order basis. Overall, the emphasis remains on minimizing waste through donations, alternative uses, or price adjustments while adhering to health regulations for disposal. Mathe (2023), highlights how conservation agriculture helps to increase food security and decrease food waste.

Table 4- 4: Methods for Ensuring Produce Quality and Freshness.

How do they ensure the quality and freshness of produce	Percentage of Participants (%)
Proper packaging	19
Temperature controlled storage	11
Quick delivery	32
Quality check	19
Sell to homes	0,5
Don't take specific measures	45,5

The key informative interviews indicated that climate change is negatively impacting food supply and security in the province, leading to crop failures, reduced yields, increased prices,

and decreased availability of produce. The agricultural sector has been reduced due to climate-related challenges, making farming unprofitable for smallholder farmers (Raffington, 2024). Seasonal growth disruptions and extreme weather events exacerbate the situation, causing crop damage and financial losses for farmers. To mitigate these challenges, a multifaceted approach involving government intervention, infrastructure development, financial support, and education is essential (Rusmayandi *et al.*, 2023). This raises concerns about future food security and sustainability.

Government intervention and support are crucial for smallholder farmers to mitigate climate change impacts (Davis *et al.*, 2020). Infrastructure development, such as flood management and protective structures, can reduce vulnerability. Financial and material assistance, such as subsidies for seeds and fertilizers, and NGOs' support, can reduce production costs. Education and training on climate change adaptation are essential. Economic considerations, such as affordable production and transportation costs, can help farmers market their produce effectively (Akinola *et al.*, 2020).

South Africa's farming sector is facing a decline due to high production costs, natural disasters, climate change impacts, and insufficient government support (Mthethwa & Wale, 2021). The aging farming population and lack of successors contribute to this decline. New farmers, displaced by COVID-19, struggle to sustain their businesses. Traditional buyers are shifting to canned and frozen foods, while informal traders and street vendors are gaining popularity. This is due to it being more affordable (Eurobarometer, 2019).

The fresh produce market is undergoing significant changes due to evolving consumer preferences, economic challenges, and the expansion of the informal trading sector. The COVID-19 pandemic has significantly disrupted this supply chain, affecting international travel, logistics, supplier production, and stockpiles, leading to shortages and higher prices for basic food items (Omoruyi *et al.*, 2022). Informal food traders, such as hawkers and stall owners, play a vital role in providing food to informal settlements and high-density areas in South Africa (Duma & Utete, 2023). Collaboration and integration within the supply chain have been shown to improve the responsiveness of fast-moving consumer goods manufacturers and retailers to customer needs (Ruthven & O'Rourke, 2020). These dynamics highlight the complexity of the current challenges facing the agricultural sector and the fresh produce market in South Africa. Addressing these issues requires a holistic approach that considers the intertwined impacts of climate change, economic pressures, and changing consumer behaviour on food security and agricultural sustainability.

4.4. Conclusion and recommendations

This study aims to map the food supply chain in KwaZulu-Natal, South Africa, to identify inefficiencies, bottlenecks, and areas for improvement. The region is home to many smallholder farmers who face challenges in organic crop production and integration into formal supply chains. The study also seeks to address food insecurity and explore the potential of short food supply chains (SFSCs) for creating a more sustainable food system. By mapping the supply chain, the research aims to bridge knowledge gaps, strengthen the resilience of the food supply chain, and improve food security and nutrition outcomes for local populations. The study was conducted across all 11 districts of KwaZulu-Natal, with surveyed respondents comprising smallholder vegetable farmers growing crops such as spinach, cabbage, dry beans, and green beans.

The study of the food supply chain in KwaZulu-Natal reveals several critical challenges faced by smallholder vegetable farmers. Among these challenges are an ageing farming population, limited market access, logistical inefficiencies, and the underutilization of educational assets due to systemic barriers. These challenges are compounded by the effects of climate change, leading to reduced agricultural productivity, increased costs, and heightened food insecurity. The findings underscore the need for targeted interventions to address these multifaceted issues and ensure the sustainability of the food supply chain in the region.

One notable conclusion from the study is the impact of farming experience and education on productivity. While experience is an asset, many farmers struggle to maximize their land's potential or adopt modern farming practices due to their age and limited access to extension services. The educational background of the farmers, though moderate with many having completed secondary education, is not fully leveraged. Systemic barriers prevent these farmers from accessing the resources and technologies necessary to improve their farming outcomes, highlighting a significant area for intervention.

The study also identifies vegetable farming as the predominant agricultural activity among the respondents. This focus on vegetables is driven by favourable environmental conditions and market demand. However, the study emphasizes the importance of promoting agricultural diversity, including grain and livestock farming, to enhance the resilience of the food system. This diversification is crucial for mitigating risks associated with environmental changes and market fluctuations, thereby contributing to a more robust and sustainable food supply chain.

Moreover, the study sheds light on the complexities and vulnerabilities within the food supply chain. Many smallholder farmers operate outside formal supply networks and face significant

challenges related to transportation, market access, and the adverse effects of climate change. The rise of informal traders has also shifted market dynamics, often driven by high unemployment rates and the need for alternative sources of income. These factors collectively contribute to the precariousness of the food supply chain in KwaZulu-Natal.

The study concludes with a call for targeted interventions to address these challenges. It emphasizes the need for government intervention, infrastructure development, financial support, and education on climate resilience. A holistic approach that integrates these elements is essential for improving the sustainability and resilience of the food supply chain, thereby ensuring that smallholder farmers can thrive in a changing and challenging environment.

4.5. Recommendations

To address the challenges identified, the study recommends several targeted interventions. Firstly, there is a need to support ageing farmers by introducing labour-saving technologies and providing training programs designed to enhance their technical efficiency. By doing so, these farmers can maintain productivity and be encouraged to adopt innovative farming practices that are essential for the sustainability of their operations.

Enhancing market access for smallholder farmers is another critical recommendation. The development of cooperatives or direct marketing channels can reduce the reliance on intermediaries, thereby improving farmers' bargaining power and leading to more stable incomes. By better integrating farmers into formal supply networks, these initiatives can also contribute to the overall stability and efficiency of the food supply chain. NGOs and private buyers can facilitate the establishment of cooperatives and direct marketing platforms, reducing the reliance on intermediaries and increasing farmers' incomes.

Promoting agricultural diversity is a further recommendation of the study. Encouraging farmers to diversify into less common agricultural practices, such as grain and livestock farming, can help mitigate risks associated with environmental changes and market fluctuations. This diversification is vital for building the resilience of the food system and ensuring that it can withstand various external shocks. This should be championed by government agencies and NGOs through training, subsidies, and pilot projects to reduce environmental and market risks.

In addition to these interventions, the study calls for investments in infrastructure and logistical support. Improvements in transportation and the development of cold storage facilities are essential for addressing logistical inefficiencies and reducing post-harvest losses. These

infrastructure investments are critical for ensuring the sustainability of the food supply chain and enhancing the overall food security in KwaZulu-Natal. This falls under the responsibility of local municipalities and government agencies, whose support is critical for minimizing post-harvest losses and improving supply chain efficiency.

Expanding educational outreach and extension services tailored to the specific needs of smallholder farmers is another key recommendation. This should be spearheaded by government agencies, in collaboration with research institutions and NGOs, to ensure smallholder farmers can adapt to and withstand climate variability. Empowering farmers with the knowledge and skills needed to adopt new technologies and improve productivity is crucial for the long-term sustainability of their farming operations. This recommendation also aligns with the need to fully leverage the educational background of farmers, which is currently underutilized.

Finally, the study recommends the implementation of climate resilience strategies. Promoting the use of drought-resistant crops and improving water management practices are essential for mitigating the impacts of climate change on agricultural productivity. These strategies are crucial for ensuring that smallholder farmers can continue to produce food sustainably in the face of increasingly variable and extreme weather conditions.

These findings directly support the thesis's broader objectives by illustrating how limited engagement in formal supply chains contributes to key vulnerabilities such as income volatility and food insecurity. The predominance of informal market participation constrains farmers' ability to secure stable prices, access consistent buyers, and integrate into resilient agricultural networks, factors that are further explored in later chapters focusing on livelihood impacts and food security dynamics in the context of climate change.

4.6. Implications for Further Research

The findings of this study open up several avenues for further research. One potential area for future investigation is the long-term dynamics of the food supply chain in KwaZulu-Natal, particularly in response to climate change and evolving market conditions. Longitudinal studies could provide valuable insights into how these dynamics change over time and how interventions can be adapted to maintain the resilience of the food supply chain.

Another area for further research is the impact of policy interventions aimed at improving the sustainability and resilience of smallholder farmers. This research could involve assessing the

effectiveness of government support programs, infrastructure investments, and educational initiatives in addressing the challenges identified in this study. Understanding the impact of these interventions could inform the development of more effective strategies for supporting smallholder farmers.

The study also suggests the need for in-depth research into the role of informal markets in the food supply chain. Exploring how these markets affect smallholder farmers and market dynamics could provide important insights into how to better integrate informal traders into formal supply chains. This research could help develop strategies to ensure that the benefits of formal market integration are extended to all participants in the food supply chain.

Additionally, the study highlights the importance of understanding the barriers and facilitators to the adoption of technological innovations among smallholder farmers. Further research in this area could provide valuable information on how to promote the use of modern farming techniques and technologies, which are essential for improving productivity and sustainability in the agricultural sector.

Finally, assessing the sustainability of existing Short Food Supply Chains (SFSCs) in KwaZulu-Natal could provide important insights into best practices that can be scaled up. This research could contribute to the development of more localized and efficient food systems, which are essential for enhancing food security and reducing the environmental impact of food production and distribution.

4.7. Limitations of this study

The study faced several limitations, including potential biases in self-reported data and the representativeness of the sample size. While the sample provides initial insights, it may not fully capture the diversity of experiences within the entire population of smallholder farmers and market agents in KwaZulu-Natal. Additionally, the four-month data collection period might not account for seasonal variations affecting the food supply chain.

4.8. Declarations

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CHAPTER 5

EVALUATING THE ASSOCIATION OF CLIMATE CHANGE PERCEPTIONS ON THE INCOME OF SMALLHOLDER VEGETABLE FARMERS, IN KWAZULU-NATAL PROVINCE, SOUTH AFRICA.

Merishca Naicker¹, Denver Naidoo¹, Simphiwe Innocentia Hlatshwayo² and Mjabuliseni Simon Ngidi²

1. African Centre for Food Security (ACFS), School of Agriculture Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg 3201, South Africa.
2. Department of Agricultural Extension and Rural Resources Management, School of Agriculture Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg 3201, South Africa.

* Correspondence: ngidim@ukzn.ac.za

Abstract: Smallholder vegetable farmers in South Africa's KwaZulu Natal Province face increasing climate variability, including erratic rainfall, droughts, and flooding, which jeopardize agricultural productivity, household income, and food security. These challenges are particularly severe for resource-poor farmers reliant on rain-fed systems, yet little empirical research has evaluated how farmers' perceptions of climate change influence their adaptive responses and income outcomes. This study addresses this gap by assessing the relationship between climate change perceptions and income among smallholder vegetable farmers. A structured quantitative research design was employed. Data was collected through a cross-sectional survey of 200 farmers selected using stratified random sampling. Descriptive statistics and econometric analyses were conducted using Seemingly Unrelated Regression (SUR) and Box-Cox models to evaluate the impact of socio-economic and perceptual factors on income and adaptive capacity. Results revealed that 69% of farmers identified crop failure and 84% reported reduced yields over the past decade due to climate variability. The SUR model showed that marital status, land ownership, sandy and silt soil types, and participation in food networks positively influenced crop management. In contrast, larger household sizes, exclusive dependence on farming, and membership in farmer associations were associated with lower adaptive capacity. The Box-Cox model highlighted that farming experience and land tenure increased income, while sole dependence on farming and certain soil conditions reduced it. These findings suggest that while farmers are aware of climate impacts, their capacity to respond effectively is shaped by a complex mix of structural and behavioural

factors. The study recommends tailored climate education, adoption of climate-smart practices, and improved access to financial and digital resources to enhance economic resilience. These insights contribute to the design of targeted adaptation strategies for vulnerable smallholder farming communities.

Keywords: Climate change, income share, smallholder Farmers, Vegetable, Perceptions

5.1. Introduction

Agriculture remains a cornerstone of South Africa's economy and rural development, not only contributing significantly to food production but also providing employment and income-generating opportunities for millions (Zhao, 2023). Within this sector, smallholder farming plays a pivotal role, engaging over two million households and supporting approximately four million individuals (Zantsi & Bester, 2019). Recognising this, the National Development Plan 2030 has explicitly prioritised smallholder agriculture as a key mechanism to alleviate rural poverty, enhance livelihoods, and stimulate inclusive economic development, particularly within former homelands (Chikozho & Milondzo, 2019). These areas, however, are often characterised by structural disadvantages such as limited land tenure security, poor infrastructure, and inadequate access to inputs and markets.

Despite these constraints, smallholder farmers continue to produce critical food crops such as spinach, maize, and other vegetables, which are essential for both subsistence and market-oriented livelihoods (Sigigaba *et al.*, 2021; Mdoda *et al.*, 2022). However, the viability of smallholder agriculture is increasingly being threatened by the multifaceted impacts of climate change. These farmers, who are predominantly resource-poor and reliant on rain-fed systems, are especially vulnerable due to their limited capacity to implement technological or financial adaptation mechanisms (Workalemahu & Dawid, 2021; Zondi *et al.*, 2022; Tantoh, 2023).

KwaZulu-Natal (KZN) Province, with its climatic variability and socio-economic disparities, provides a critical context for examining the intersection of smallholder livelihoods and climate risk. The region has already experienced an increase in extreme weather events, shifting rainfall patterns, prolonged droughts, and rising temperatures, all of which have severe implications for agricultural productivity, soil fertility, and income generation (Darge, 2023). These climatic shifts have also contributed to increased pest and disease outbreaks, shorter growing seasons, and declining yields, particularly in vegetable farming systems, which are highly sensitive to environmental fluctuations.

In response to these stressors, smallholder farmers are developing adaptive strategies, yet the effectiveness and implementation of these strategies are often shaped by how farmers perceive

climate change. Perception of climate change refers to an individual's awareness, understanding, and interpretation of changes in long-term weather patterns and environmental conditions. These perceptions are not uniform but are influenced by multiple socio-economic and institutional factors, including age, education level, farming experience, income, land ownership, and access to extension services (Temba, 2023). For example, farmers who perceive increased climatic risks, such as erratic rainfall, droughts, and flooding, are more likely to adopt adaptive behaviours like altering planting schedules, diversifying crops, or investing in drought-resistant varieties and water conservation techniques (Asare-Nuamah & Botchway, 2019; Darge, 2023).

Farmers' perceptions thus function as both cognitive and behavioural filters through which climate signals are interpreted and responded to. These perceptions influence not only immediate farming decisions but also long-term investments and risk management strategies. Understanding how smallholder farmers perceive climate change is therefore vital for identifying barriers and enablers to climate-resilient agriculture, particularly in regions where institutional support systems remain fragmented or under-resourced. Moreover, these perceptions play a critical role in shaping livelihood outcomes, including income stability, which is increasingly under threat from climate variability.

Despite increasing research attention to the vulnerability of smallholder farmers and the necessity of climate-smart agriculture, there remains a notable gap in the literature regarding the direct relationship between climate change perceptions and income outcomes (Mufudza & Gukurume, 2021; Rapholo & Makia, 2020). While previous studies have highlighted how adaptation strategies can improve resilience, few have empirically analysed how farmers' subjective understanding of climate change translates into income effects, particularly within the context of vegetable farming in KZN. This gap is especially pressing given that vegetables are both climate-sensitive and economically important for smallholder households in the province.

Prior research by Kom *et al.* (2019) and Olabanji *et al.* (2021) has demonstrated the importance of understanding farmers' behavioural intentions in designing effective climate change adaptation strategies. However, these studies have often overlooked the income-related consequences of perception-based decisions. Additionally, Born *et al.* (2019) and Senyolo *et al.* (2021) point to systemic barriers such as limited access to credit, agricultural insurance, and market information that constrain adaptive capacity and income potential. These insights underscore the urgency of evaluating climate change perceptions not only as cognitive constructs but as socio-economic determinants of agricultural success and resilience.

This study, therefore, aims to evaluate the impact of climate change perceptions on the income of smallholder vegetable farmers in KwaZulu-Natal Province, South Africa. It seeks to answer the following central question: How do smallholder farmers' perceptions of climate change affect their adaptive decisions and income outcomes? In addressing this question, the research contributes to a nuanced understanding of the climate-agriculture-income nexus, offering policy-relevant insights into how perception-informed adaptation can support the development of more resilient and economically viable smallholder farming systems in climate-vulnerable regions.

5.1.1. Theoretical underpinnings

The Sustainable Livelihoods Framework (SLF), originally developed by the Department for International Development (DFID, 1999), provides a comprehensive lens for understanding how rural households mobilise resources and respond to vulnerabilities to sustain their livelihoods. The framework identifies five key capital assets, human, natural, financial, physical, and social, which households utilise to pursue livelihood strategies aimed at achieving desired outcomes such as increased income, food security, and resilience to shocks.

In the context of smallholder vegetable farming in KwaZulu-Natal, perceptions of climate change represent a crucial element of human capital, which refers to the knowledge, skills, and capabilities that enable individuals to adapt and make informed decisions. Perception of climate risks plays a foundational role in shaping farmers' behavioural responses, risk mitigation strategies, and long-term livelihood planning (Mertz *et al.*, 2009). When farmers perceive climate change as a significant threat, they are more likely to adjust their agricultural practices, diversify crops, adopt adaptation technologies, or seek supplementary income sources (Bryan *et al.*, 2013). Conversely, limited or inaccurate perceptions may result in maladaptive practices or missed opportunities, ultimately constraining income-generating potential.

The SLF posits that livelihood outcomes, such as household income, are directly influenced by the dynamic interaction between capital assets and the vulnerability context, which includes climate variability and change. Perceptions of climate change serve as an interpretive filter through which farmers assess risks and opportunities within this vulnerability context. These perceptions thus mediate how other capital assets, such as financial resources to invest in irrigation (physical capital), or access to weather-related information through farmer networks (social capital), are utilised to respond to climate threats.

Furthermore, livelihood strategies, defined as the choice's households make to achieve their goals, are critically shaped by the extent to which farmers perceive climate change as a credible and immediate concern. A well-informed perception can trigger proactive strategies such as crop diversification, water harvesting, or engagement with climate-smart agricultural interventions, all of which can positively influence income levels (Below *et al.*, 2012). On the other hand, scepticism or denial about climate change can delay adaptive responses, increasing susceptibility to climate shocks and reducing farm productivity and income.

In summary, within the SLF, perceptions of climate change are not merely cognitive constructs; they are active determinants of adaptive capacity and income outcomes. By evaluating the association between climate change perceptions and income among smallholder vegetable farmers in KwaZulu Natal, this study advances a nuanced understanding of how human capital interacts with broader livelihood systems. It underscores the imperative of integrating perception-based indicators into policy interventions that aim to enhance climate resilience and sustainable rural development.

5.2. Methodology

5.2.1. Description of study area

This study was conducted in KZN, a province in South Africa. The dry months are experienced in June, and the wet season is experienced in January when high rainfall occurs (KZN Municipalities,2024). Agriculture plays a vital role in the rural areas of KZN as it employs the surrounding communities. KZN has a total of 6.5 million hectares of land for farming purposes, and of that percentage, 82% is suitable for extensive livestock production. The study was conducted between December 2023 and March 2024 and focused on smallholder farmers within the province. The average temperature experienced in KZN is 21 °C (KZN Municipalities,2024). The typical amount of rainfall that is experienced is approximately 106.56 millimetres annually. The province has a mixed economy, with the key sectors being agriculture, tourism, and manufacturing. The province consists of 11 districts that were surveyed as illustrated in Figure 5-1. The study population was largely male, and the ages of the surveyed smallholder farmers ranged from to 26-83 years. The study area was chosen because climatic events have significantly the farming community.

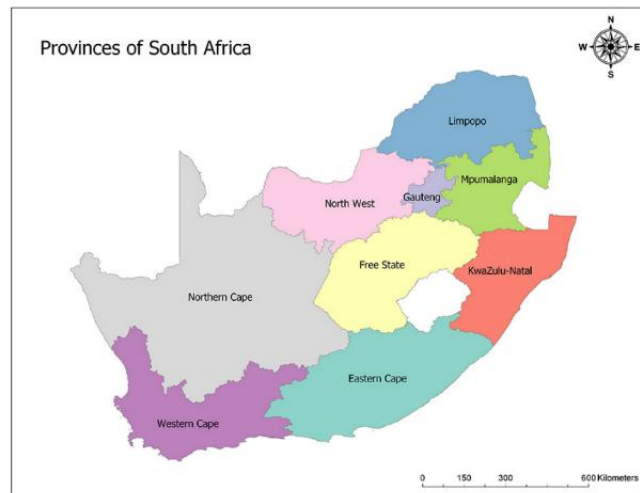


Figure 5- 1: Map showing the study area (KZN).

<https://th.bing.com/th/id/OIP.YS8RSBchUeFDFqX9Blm96AHaHs?rs=1&pid=ImgDetMain>

5.2.2. Research design

This study adopted a quantitative research design to evaluate the association between smallholder vegetable farmers' perceptions of climate change and their income outcomes in KwaZulu-Natal Province, South Africa. This design was chosen for its ability to capture a snapshot of farmers' socio-economic conditions, climate perceptions, and adaptive behaviours at a specific point in time, enabling correlation and regression analyses (Creswell & Creswell, 2021).

A structured questionnaire was administered to 200 smallholder vegetable farmers, selected using stratified random sampling from a population of 2,530 registered farmers. A 95% confidence interval was employed with a 5% margin for error. This sampling technique is characterized by its simplicity and fairness, as it provides an unbiased way to select participants from a larger population (Asrial *et al.*, 2022). Farmers included in the study were actively engaged in vegetable production and registered with local agricultural organisations or market operators. While selecting farmers registered with local agricultural organizations may have excluded the unregistered farmers, these farmers share similar characteristics (Beharielal *et al.*, 2022).

The survey instrument collected data on demographic and socio-economic characteristics, climate change perceptions, adaptation strategies, and income levels. This approach ensured the inclusion of both subjective (perception-based) and objective (income, farming inputs, land tenure) variables.

To strengthen the explanatory power of the findings, two econometric models were employed:

- The Seemingly Unrelated Regression (SUR) model was used to assess how socio-economic and perceptual factors jointly influence various dimensions of adaptive capacity.
- The Box-Cox transformation model was applied to estimate the functional relationship between key predictors and income levels, accounting for non-linearity and variable distributions.

The cross-sectional design, combined with rigorous sampling and robust statistical techniques, allowed for a nuanced understanding of how climate perceptions translate into adaptive behaviour and income outcomes among smallholder farmers in a vulnerable region.

5.2.3. Sampling procedure

This study employed a purposive sampling approach to select participants actively engaged in vegetable production and directly affected by climate change in KwaZulu-Natal. Purposive sampling enabled the deliberate selection of individuals possessing relevant traits and experiences critical to the research focus (Yanan, 2024). A total of 200 smallholder farmers were purposively chosen from all 11 districts of the province, identified through local agricultural extension offices and market directories to ensure representation across diverse agro-ecological zones and farming practices.

By focusing solely on questionnaire data, the study prioritized breadth and representativeness across the farming communities most affected by climate variability in the region.

5.2.4. Data collection

A quantitative method is used in this study. This method helps test hypotheses because it allows researchers to use statistical tools to examine data and arrive at conclusions that are supported by evidence (Yuan & Liu, 2022). The data were collected between December 2023 and March 2024. The data collected from the respondents were socioeconomic, demographic, climatic, and income information. A sample size of 200 smallholder farmers was used in the questionnaire. The questionnaire was distributed to 200 smallholder vegetable farmers through field visits and community meetings to ensure a broad and diverse sample.

The questionnaire structure incorporated closed-ended questions, such as Likert scale items and multiple-choice questions, to facilitate quantitative analysis and open-ended questions to capture qualitative insights. Zulu-speaking enumerators were used when the farmer did not

understand English. After obtaining consent from the participants, the questionnaires were recorded. According to Sesar & Dodaj (2022), this approach improves research transparency and permits study replication, supporting the general validity and trustworthiness of the research outcomes.

Simple random sampling was used to guarantee varied representation of smallholder vegetable producers throughout the districts. A 5% margin of error is included in the 95% confidence interval. Because of the impartial method of selecting participants from a wider community, this sampling strategy is known for its simplicity and fairness (Zhang & Wang, 2021). This approach is especially helpful when researchers want to make findings that apply to the entire group they are studying. For the questionnaires, 200 smallholder vegetable producers constituted the sample size. These farmers were selected based on their registration with provincial market operators or local agricultural groups. This ensured that all the smallholder farmers in the province were fully represented.

5.2.5. Data analysis

Once the data collection was completed, the questionnaires were checked for accuracy. Quantitative data and descriptive statistics were analyzed using the Statistical Package for Social Science (IBM SPSS), version 28.

To evaluate the impact of climate change perception on income while accounting for potential endogeneity, this study used two econometric techniques, namely, a Seemingly Unrelated Regression (SUR) model and a Box-Cox regression model with a control function approach, to determine the influence of climate change perception on smallholder farmers' income (Toluse & Tolulope, 2022).

In estimating factors influencing the climate change perception of vegetable farmers a seemingly unrelated regression (SUR) model was employed for the study. SUR analysis was applied to the perceived impact of climate change on livelihood of vegetable farmers. This is to acknowledge that the principal motive here is about how farmers perceived impact of climate change on their livelihoods. The SUR enables us to identify the factors of perceived impact of droughts from the five key perspectives: pest and disease infestation, hailstorms, loss of livestock and heavy rainfall (flooding). SUR is a system of equations that are correlated across equations for an individual but uncorrelated across equations. Estimating multiple equations through SUR produces consistent and efficient parameter estimates as opposed to estimating each equation separately. This is because SUR ignores the possibility of the residuals of the equations being correlated.

Also, while estimating the impact of climate change perception on income of vegetable farmers, a Box-Cox regression model with control function approach was used. The control function approach was used to correct for endogeneity which was predicted from the seemingly unrelated regression. When endogeneity is present, ordinary regression techniques produce biased and inconsistent estimators. There exist several approaches to solve the endogeneity issues: ESR, PSM and Control function approach. The adopted technique for this study is based on control function approach. Since the control function needs to be estimated in a first step (SUR). Therefore, the framework for this study can be viewed as a semiparametric transformation model with generated covariates that extends the setting of Linton *et al.* (2008) who consider full exogeneity. A control variable is such that the error term in the model is conditionally unrelated to the explanatory variables given this control variable, whereas without conditioning on this variable the explanatory variables (or at least the endogenous ones) would be related to the error term. Hence, control variable (predicted residual) reestablishes the desirable property that the covariates and the error term are not related, which is crucial to correct for endogeneity.

The income from vegetable farming is expressed as annual income in Rands and is the dependent variable in the Box-Cox model. The SUR model was applied to develop a climate change perception index, which was used as the independent variable (Toluse & Tolulope, 2022). The Box-Cox model's control variables included gender, age, education level, marital status, position in the household, household size, number of years of farming, farming main source of income, total land size owned, total land size used for agricultural production, type of soil, member of farmers' association, and involvement in a formal or informal food supply chain network.

5.2.3.1. Seemingly Unrelated Regression (SUR) model

The SUR model was employed to address potential correlations between errors in climate change perception equations. It assesses how the climate change perception index relates to independent variables, exposing the impact of each factor on smallholder farmers' perceptions of climate change (Zuehlke, 2021).

Let y_{i1} indicate the climate change perception of smallholder farmer i , and X_i symbolize the set of independent variables. The SUR model is specified as

$$y_{i1} = \beta_0 + \beta_1 X_i + u_{i1}$$

where u_{i1} is the error term in the equation? If different components of how smallholder farmers perceive the climate are considered, more equations may be included.

5.2.3.2. Box-Cox regression model.

The Box-Cox regression model was used to transform the dependent variable to address the issues of nonlinearity and heteroscedasticity. A control function approach was employed to correct for endogeneity, predicted using the SUR model (Liu *et al.*, 2020). This requires estimating the residuals from the SUR model and including them as an additional regressor in the Box-Cox model to account for the potential endogeneity between climate change perception and income. The Box-Cox regression is a statistical technique used to correct skewed data and make it more normally distributed, which improves the accuracy of regression analysis. This is particularly important when analyzing income data, which often displays skewness due to a concentration of lower-income households and fewer high-income outliers. By transforming the data to approximate a normal distribution, the Box-Cox model helps ensure more reliable and interpretable results. To evaluate the impact of climate change perception on income, a Box-Cox regression model was utilized, which allowed for flexible modelling of the dependent variable through transformation (Parker & Mazzini, 2021). The control function approach was integrated to address potential endogeneity in climate change perception, which may be correlated with unobserved factors affecting income (Loaiza *et al.*, 2023).

The climate change perception variables were operationalised using a structured questionnaire consisting of Likert scale items, where respondents indicated their level of agreement with statements related to observable environmental changes, such as temperature shifts, rainfall patterns, drought frequency, and extreme weather events. To enhance measurement validity, these items were analysed using exploratory factor analysis (EFA), which identified latent constructs that represent broader perception dimensions, such as awareness of temperature changes or concerns about rainfall variability. This analytical approach reduced data complexity by grouping related items, thereby strengthening the internal consistency and construct validity of the variables. Overall, this method contributed to greater transparency and reproducibility in the measurement of farmers' climate change perceptions.

5.2.3.2.1. Estimating Endogeneity

The first stage involved estimating the climate change perception model using the SUR approach to obtain the residuals.

$$y_{i1} = \beta_0 + \beta_1 X_i + u_{i1}$$

5.2.3.2.2. Box-Cox Regression with Control Function

The Box-Cox model for income is indicated as:

$$y_{i2} = \lambda \left(\frac{I_i^\theta - 1}{\theta} \right) + \gamma_0 + \gamma_1 y_{i1} + \gamma_2 Z_i + v_i$$

where y_{i2} is income, λ is the Box-Cox transformation parameter, θ represents the Box-Cox transformation parameter for income, Z_i comprises control variables, and v_i is the error term.

To correct for endogeneity, the residuals δu_{i1} from the SUR model were entered as an additional explanatory variable:

$$y_{i2} = \lambda \left(\frac{I_i^\theta - 1}{\theta} \right) + \gamma_0 + \gamma_1 y_{i1} + \gamma_2 Z_i + \delta u_{i1} + v_i$$

The Durbin-Watson and Breusch-Pagan tests were included in the SUR model diagnostic test to check for heteroscedasticity and autocorrelation. The Hausman test was used for the Box-Cox model and the Ramsey RESET test for model specification, endogeneity, and functional form (Parker & Mazzini, 2021). To verify the consistency of the results, robustness tests were required to change the model's parameters and re-estimate them. Sensitivity analysis was conducted by evaluating different Box-Cox transformation specifications (Zuehlke, 2021).

Perception variables in this study were developed to capture smallholder farmers' subjective understanding and experiences of climate-related risks and agricultural challenges. Data was collected through a structured questionnaire administered during field surveys, which included items asking respondents whether they had observed specific events or conditions, such as increased pest prevalence, hailstone damage, erratic rainfall, and soil fertility decline, over the past five to ten years. Farmers were asked to respond using a binary scale, where "1" indicated recognition or concern about a particular issue, and "0" indicated no recognition or concern. These binary variables were used to construct key perception indicators, which served as dependent variables in logistic regression models. This approach allowed for an assessment of

the relationship between individual and farm-level characteristics and the likelihood of perceiving specific environmental and agronomic risks.

5.3. Results and discussion

5.3.1. Descriptive Results

5.3.1.1. Demographic characteristics of smallholder farmers in KwaZulu-Natal.

The sociodemographic profile of smallholder vegetable farmers in KwaZulu-Natal (Table 5-1) offers a foundational lens through which to interpret the more complex econometric relationships examined in Tables 5-2 and 5-3. The sample is predominantly male (65%), with an average age of 40–53 years and 50.5% having completed secondary education. These characteristics shape not only farming practices but also perceptions of and responses to climate change, as well as resultant income levels.

Gender, while prominent in the descriptive data, did not significantly predict climate change perceptions (Table 5-2) nor income levels (Table 5-3). This suggests that while males dominate the farming population, their gender alone does not substantially alter how they perceive or economically respond to climate-related risks. Similarly, age was negatively associated with climate change perceptions across all five indicators (pests, diseases, hailstones, heavy rain, and livestock) in Table 5-2, though these results were not statistically significant. In the income model (Table 5-3), age again had a negative but non-significant coefficient. This consistency across models suggests that older farmers may be less perceptive and less economically resilient to climate risks, although the statistical insignificance tempers strong conclusions. These patterns align with existing literature showing that younger farmers are generally more responsive to environmental changes due to greater openness to innovation (Below *et al.*, 2012; Fosu-Mensah *et al.*, 2012).

Education level presents a more nuanced picture. While not statistically significant across all climate perception indicators, it was positively associated with the perception of hailstones as a climate threat (Table 5-2), indicating that more educated farmers may be better able to recognize or process specific climate phenomena. In the income model (Table 5-3), education had a positive but insignificant coefficient, implying that education improves awareness but does not directly translate to higher income under climate stress. This supports findings from Myeki & Bahta (2021), who argue that education enhances adaptive awareness, even if structural constraints limit the economic returns on that knowledge.

The analysis reveals stronger and statistically significant relationships for other variables. For example, marital status was significantly associated with the perception of pests (Table 5-2), potentially due to the social and economic stability marriage provides, which may enhance attentiveness to environmental risks. However, marital status was not significantly related to income (Table 5-3), suggesting that while it influences perception, it does not directly enhance economic resilience.

Farm-level characteristics offer clearer patterns. The total size of land used for farming significantly increased the likelihood of perceiving climate threats (pests, diseases, and heavy rain) in Table 5-2, implying that a larger operational scale enhances exposure and sensitivity to climate variability. Similarly, total land owned significantly and positively influenced income ($p < 0.01$) in Table 5-3. This consistent pattern across perception and income models reinforces the role of land access in shaping both awareness and adaptation outcomes (Arslan *et al.*, 2015).

Farming experience, measured by the number of years growing vegetables, was significantly and positively associated with income ($p < 0.05$) in the Box-Cox regression model. While it did not significantly influence perception in Table 5-2, the positive income effect suggests that experiential knowledge strengthens economic returns under climate stress, even if it does not heighten awareness of specific risks. This is in line with evidence from Mertz *et al.* (2009) that experience fosters adaptive capacity.

A particularly notable finding is that farmers whose main source of income is agriculture were significantly less likely to perceive hailstones as a climate risk (Table 5-2, $p < 0.05$) and had lower income levels (Table 5-3, $p < 0.1$). This suggests a possible desensitization or risk normalization effect, where farmers overly reliant on agriculture underplay certain risks to maintain productivity focus. It also reflects the vulnerability of undiversified income strategies to climate impacts, as documented by Barrett *et al.* (2001).

Finally, participation in food supply chains or networks was positively associated with awareness of multiple climate risks (Table 5-2), including pests ($p < 0.1$), heavy rains ($p < 0.05$), and livestock impacts ($p < 0.01$). Paradoxically, this variable was associated with lower income (Table 5-3, $p < 0.1$), possibly reflecting the costs, obligations, or power asymmetries inherent in such networks. This highlights the tension between information access and economic return, consistent with Haggblade *et al.* (2010).

In summary, this analysis strengthens the narrative by showing how sociodemographic and structural factors influence both perception and income, though not always in aligned or

statistically significant ways. While some variables, such as land ownership and farming experience, show consistent positive effects across both outcomes, others (e.g., age, education, income reliance) influence either perception or income, but not both. These patterns highlight the complex interplay between awareness, adaptation, and economic resilience in smallholder farming systems under climate change.

Table 5- 1: Demographics of the surveyed population.

Variable		Frequency (n=200)	Percentage (%)
Gender	Male	130	65
	Female	70	35
Age	26-39	45	22,5
	40-53	60	30
	54-67	56	28
	68-81	34	17
	82-88	5	2,5
The education level of respondents	No Formal Education	12	6
	Primary	50	25
	Secondary	101	50,5
	Tertiary & above	37	18,5
Is farming the main source of income	Yes	170	85
	No	30	15
Have you experienced low vegetable yields over the past 10 years?	Yes	168	84
	No	31	15,5
	lo not know	1	0,5
Number of days you supply produce?	1 day	32	16
	2 days	89	44,5
	3 days	57	28,5
	4 days	14	7
	5 days	6	3
	6 days	2	1
	7 days	0	0
Do you transport your produce yourself?	Yes	166	83
	N0	34	17
What is the main impact that you feel climate change has?	Crop failure	138	69
	ood Insecurity	51	25,5
	ange in weather patterns	1	0,5
	Do not Know	10	5

5.3.1.2. Perception of climate change by the surveyed smallholder farmers

The study's analysis of climate change perceptions reveals a complex landscape of environmental challenges experienced by smallholder farmers (Figure 5-2). Respondents identified multiple climate-related phenomena, with frequency and severity varying across observed indicators.

Extreme weather events emerged as the most prominent climate change manifestations. Frequent floods were reported by 81.5% of respondents, closely followed by excessive temperatures (76%) and alterations in rainfall patterns (66.5%). These findings underscore the significant environmental volatility confronting agricultural communities in the region.

Waterlogging presented a notable secondary challenge, with 35% of participants identifying it as a critical climate change impact. The findings align with Hefele (2020) research, which found that waterlogging substantially compromises agricultural productivity through multiple mechanisms, including reduced crop yields, soil degradation, increased pest and disease proliferation, and operational complications during planting and harvesting cycles.

Comparatively, excessive cold was less frequently reported, with only 24% of respondents acknowledging its presence. A subset of participants (12.5%) demonstrated uncertainty or limited comprehension of climate change manifestations, potentially indicating knowledge gaps or perceptual ambiguities.

The observed trends align with broader global climate change trajectories, characterized by temperature increases and precipitation pattern disruptions that systematically impact agricultural and ecological systems (Woldeselassie *et al.*, 2021; Zikhali *et al.*, 2021). The high prevalence of flooding and waterlogging suggests significant regional vulnerabilities, potentially stemming from inadequate water management infrastructure or heightened precipitation variability (Olabanji *et al.*, 2021).

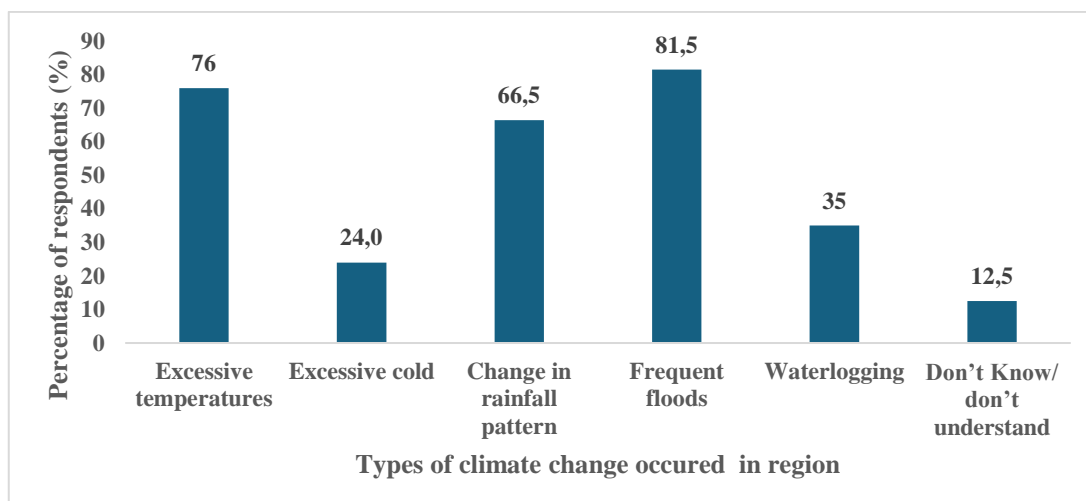


Figure 5- 2: Perceptions of climate change by respondents

5.3.2. Empirical Results

5.3.2.1. Determinants of the factors that influence the climate change perception of the smallholder farmers using the Seemingly Unrelated Regression Model.

Table 5-2 shows factors influencing the climate change perception of Smallholder vegetable farmers in KZN using the seemingly unrelated regression model. The seemingly unrelated regression model revealed nuanced insights into factors influencing climate change perception among smallholder vegetable farmers. Marital status demonstrated a positive and significant relationship with pest-affected crop outcomes. Contrary to existing literature, this suggests married farmers may experience reduced pest impacts, diverging from Hlatshwayo *et al.* (2021) findings that attributed better resource access to marital support networks. Household size exhibited a significant negative correlation with crop disease prevalence. Larger households showed increased disease complexity, supporting research by Okonya *et al.* (2019) and Agyeman-Boaten & Fumey (2021) that emphasizes how crop diversification while mitigating failure risks, introduces management challenges and potential economic stress. Farmers primarily dependent on agricultural income demonstrated a statistically significant negative impact concerning hailstone-related crop damage. This finding corroborates studies by De Lange (2021) and Moyo & Moyo (2020), highlighting the elevated vulnerability of income-dependent farmers to extreme weather events and consequent economic precarity. The analysis underscores the intricate interplay between socioeconomic factors and agricultural resilience, emphasizing the need for contextualized, multidimensional adaptation strategies.

Table 5- 2: Factors influencing the climate change perception of Smallholder vegetable farmers in KwaZulu-Natal- seemingly unrelated regression model.

	pest		disease		hailstone		Heavy rains		livestock	
	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.
Gender	0.013	0.067	-0.029	0.059	0.099	0.073	0.005	0.060	-0.002	0.069
Age	-0.003	0.004	-0.005	0.003	-0.002	0.004	-0.002	0.003	0.004	0.004
Education Level	-0.041	0.047	0.050	0.041	0.079	0.051	0.033	0.042	-0.015	0.049
Marital status	0.088	0.042**	0.042	0.037	-0.032	0.045	0.057	0.037	0.058	0.043
Position in household.	0.006	0.022	-0.007	0.020	0.014	0.024	0.026	0.020	0.028	0.023
Household size	-0.017	0.013	-0.019	0.011**	0.001	0.014	-0.014	0.011	-0.005	0.013
Number of years farming -vegetables	-0.003	0.004	0.002	0.003	0.003	0.004	0.000	0.003	-0.004	0.004
Is farming your main source of income.	0.060	0.090	-0.004	0.079	-0.235	0.098**	-0.016	0.080	0.024	0.093
Total size of land owned (hectare)	-0.002	0.003	-0.006	0.003**	0.004	0.003	-0.007	0.003**	0.001	0.003
Total size of land used for Farming.	0.013	0.007*	0.016	0.006**	0.002	0.008	0.017	0.007**	-0.021	0.007***
Type of soil - Sand	-0.033	0.077	0.092	0.067	0.167	0.084**	0.017	0.069	0.022	0.079
Type of soil- Silt	0.145	0.082*	0.123	0.071*	0.080	0.089	0.076	0.073	0.136	0.084
Type of soil – Clay	-0.048	0.081	-0.066	0.071	-0.067	0.088	-0.054	0.072	0.019	0.083
Type of soil -Loam	0.104	0.079	0.081	0.069	0.028	0.086	0.023	0.071	-0.109	0.082
Are you a member of a farmers' association/ co-operation?	-0.033	0.024	-0.037	0.021*	-0.009	0.026	-0.015		-0.083	0.024***
Involved in any formal or informal food supply chain networks or associations	0.169	0.070*	0.067	0.061	0.022	0.076	0.140	0.063**	0.196	0.072***
cons	0.288	0.512	0.568	0.449	-0.031	0.557	0.431	0.458	0.037	0.528

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Equation	Obs	Params	RMSE	R-squared	chi2	P>chi2
Pest	200.000	16.000	0.419	0.110	24.620	0.077
disease	200.000	16.000	0.367	0.158	37.450	0.002
hailstone	200.000	16.000	0.456	0.119	26.960	0.042
Heavy rains	200.000	16.000	0.375	0.106	23.680	0.097
Livestock	200.000	16.000	0.432	0.217	55.340	0.000

The total size of land owned by smallholder farmers showed a statistically negative and significant relationship on crops that were affected by disease and heavy rains, as shown in Table 5-2. The study revealed a statistically negative and significant influence of total land size on crop vulnerability to diseases and heavy rains. Farmers with larger land areas were more likely to experience higher crop yield damage. This finding contradicts studies by Houser *et al.* (2019) and Asravor (2022), which suggested that crop damage is primarily caused by poor resource management rather than land size.

Interestingly, the total land used for vegetable farming showed a significant and positive influence on crops affected by pests, diseases, and heavy rains. Farmers with larger planted areas were less likely to experience extensive crop damage. This supports research by Agyeman-Boaten & Fumey (2021) and Deb & Dutta (2022), which found that larger farmers implement advanced agricultural practices and multi-crop systems that reduce crop damage and promote yield stability.

The study also discovered that larger farming areas correlated with increased livestock damage. This aligns with Colantoni *et al.* (2020), who noted that larger farm sizes can complicate security measures and increase the risk of livestock trampling, necessitating effective management strategies for sustainable agricultural practices.

Soil composition emerged as another critical factor. Farmers with sandy soil demonstrated reduced vulnerability to hailstones, consistent with Müller & Smith (2020), who attributed this resilience to better drainage and less compact soil structure. Similarly, silt soil showed a positive impact in reducing pests and diseases, supported by Khan & Ahmad (2019), who highlighted its superior moisture retention and nutrient availability.

Farmers' association membership presented a complex dynamic. Counterintuitively, being part of a farmers' association correlated with increased crop vulnerability to diseases and livestock damage. This observation aligns with Mavhura & Moyo (2019), who suggested that collective agricultural practices might introduce additional risks.

Participation in formal or informal food supply chain networks showed more promising results. Farmers involved in these networks experienced less extensive damage from pests, heavy rains, and livestock issues. This finding agrees with Tan *et al.* (2022), who identified benefits such as improved resource access, enhanced pest management, risk sharing, and sustainable agricultural techniques.

These insights underscore the importance of targeted interventions that support smallholder farmer resilience and food security, recognizing the intricate relationships between land use, soil characteristics, and institutional frameworks.

5.3.2.2. Impact of climate change perception on the income of smallholder vegetable farmers using the box Cox regression model with control function approach

Table 5-3 presents a summary of the Box-Cox regression estimates for the effects of climate change perception on smallholder vegetable farmers' income loss. From Table 5-3, the variable number of years in farming vegetables is farming your main source of income. The total size of land owned, type of soil sand, type of soil silt, and involvement in any formal or informal food supply chain networks, or associations had significant impacts on the income of the vegetable farmers surveyed.

The number of years of vegetable farming had a positive and significant impact on the income of surveyed farmers. This indicates that farmers with more years of experience tend to generate higher revenues. This aligns with the findings of Dhillon & Moncur (2023) and Pedersen *et al.* (2024), who suggested that farmers with more experience have better resource management, market knowledge, and advanced farming practices, enhancing their productivity and income.

Farmers who depend on farming as their main source of income had a significant and negative impact on their revenue, which is consistent with (Nwafor, 2020) who found that farmers with several sources of income may be less focused on farming, although those who depend primarily on agriculture may be more productive but experience unpredictable situations due to climatic conditions and market fluctuations that cause their income to decrease.

Table 5- 3: Impact of climate change perception on income of vegetable farmers-Box Cox regression model with control function approach.

The control function approach was used to correct for endogeneity which was predicted from the seemingly unrelated regression

Trans	Coefficient	chi2 (df)	P>chi2		df
			(df)		
Gender	0.324	0.246	0.620		1
Age	-0.848	1.442	0.230		1
Education Level	0.770	0.882	0.348		1
Marital status	-0.277	0.121	0.728		1
Position in household.	-0.073	0.040	0.842		1
Household size	-0.331	0.726	0.394		1

Number of years farming -vegetables	0.859	4.043	0.044**	1
Is farming your main source of income.	-1.745	3.205	0.073*	1
Total size of land owned (hectare)	0.906	11.107	0.001***	1
Total size of land used for Farming.	0.342	0.450	0.503	1
Type of soil - Sand	-1.430	3.868	0.049**	1
Type of soil- Silt	-2.305	3.640	0.056**	1
Type of soil – Clay	-0.094	0.014	0.904	1
Type of soil -Loam	-1.357	1.835	0.176	1
Are you a member of a farmers' association/ co-operation?	0.525	1.476	0.224	1
Involved in any formal or informal food supply chain networks or associations	-2.181	3.468	0.063*	1
residuals	1.155	0.116	0.733	1
sigma	2.835			
/lambda 	0.149	0.378		0.692
/theta 	0.103	0.044		0.021
Prob > chi2	0.000			
LR chi2(18)	79.33			
				Prob >
		log likelihood	chi2	chi2
theta=lambda	-1	-2693.536	673.650	0.000
theta=lambda	0	-2359.483	5.540	0.019
theta=lambda	1	-2511.383	309.340	0.000

The total size of land owned (hectares) had a positive and significant influence on the revenue of smallholder vegetable farmers. This indicates that farmers with larger pieces of land are more likely to earn higher incomes. This aligns with the studies conducted by Hao *et al.* (2023) and Zhang *et al.* (2024), who found that larger land sizes allow farmers to implement more adaptation strategies that enhance their productivity and income.

Farmers with sand and silt soil had a significant and negative influence on their income, as these soils may be less fertile and may cause decreased productivity and reduced income. According to Abokyi *et al.* (2020), soil type fundamentally affects agricultural productivity and farmer income, with different compositions (sand, silt, clay, and loam) affecting crop yields and suitable crops, which agrees with the findings.

Farmers' involvement in formal or informal food supply chain networks or associations also had a significant and negative influence on income. These groups are seen to enhance market access and support, and in return, should increase the revenue of smallholder farmers. The findings contrast with those of Ogutu *et al.* (2019), who state that involvement in formal food

supply chain networks increases farmers' revenue as they are exposed to better market access and customer base.

5.4. Conclusion and policy recommendations

This study examined how smallholder farmers' perceptions of climate change affected their income share. The findings revealed significant relationships between various factors and farmers' climate change perceptions and revenue. Socioeconomic attributes played a crucial role in shaping these outcomes. Several factors showed positive effects on climate change perceptions, including marital status and farms with sandy or silt soil. However, factors such as household size, farming as the main income source, total land owned, and membership in farmers' associations demonstrated negative relationships with climate change perceptions. Regarding crop impacts, the total size of vegetable production showed positive correlations with pest damage, diseases, and heavy rain effects, while negatively impacting livestock trampling incidents. The study found that farming experience (measured in years) and involvement in formal or informal food supply chain networks positively influenced farmers' income. Conversely, factors such as relying solely on farming income, total land ownership, and having sandy or silt soil types negatively impacted revenue. The findings highlight that enhancing farmers' knowledge of market participation and climate change adaptation strategies can significantly improve their revenue streams. The relationship between socioeconomic attributes and climate change perceptions proves crucial in determining smallholder farmers' income share.

Based on the findings here are tailored recommendations for subgroups of farmers:

Recommendations for Younger and Less Experienced Farmers

- Implement capacity-building initiatives such as:
 - Farmer Field Schools
- Mentorship programs connecting them with experienced farmers
- Provide foundational training in:
 - Climate-smart agriculture
 - Financial literacy (especially in local languages)
 - Leverage their digital literacy by promoting:
 - Digital agricultural advisory tools
- Mobile-based platforms offering:
 - Real-time weather updates

- Market access information
- Pest and disease management tips

Recommendations for Older and More Experienced Farmers

- Introduce training in modern agricultural practices, including:
 - Precision agriculture
 - Solar-powered irrigation systems
 - Labor-saving technologies
- Encourage their participation in knowledge-sharing platforms to:
 - Share traditional and locally adapted best practices
 - Stay updated on new, productivity-enhancing technologies
 - Promote tools and practices that reduce workload while maintaining or boosting yields

Recommendations for Farmers with Limited Access to Land

- Promote intensive, resource-efficient production techniques:
 - Vertical gardening
 - Intercropping
 - High-value or fast-maturing crops
- Improve access to:
 - Microfinance services
 - Subsidized agricultural inputs
 - Focus on maximizing yield per unit area to overcome space constraints

Recommendations for Farmers Managing Larger Plots

- Address complex land management needs with:
 - Integrated Pest Management (IPM) strategies
 - Precision farming tools
 - Remote sensing technologies for stress monitoring
- Support adoption of:
 - Mechanization
 - Data-driven farming systems to enhance productivity and sustainability

Recommendations for Farmers on Sandy or Degraded Soils

- Introduce soil-specific interventions such as:

- Organic soil amendments (e.g., compost, manure)
- Conservation agriculture practices (e.g., no-till, mulching)
- Crop diversification using drought-/low-fertility-tolerant varieties
- Focus on improving soil fertility and water retention to narrow income gaps driven by environmental limitations

Cross-Cutting Interventions (Applicable to All Farmers)

- Strengthen institutional support through:
 - Improved collaboration between government and NGOs
- Expand access to:
 - Agricultural insurance
 - Affordable credit and input subsidies
- Encourage the formation and strengthening of cooperatives to:
 - Promote collective action
 - Improve market access and bargaining power
 - Foster resilience through shared knowledge and resources

By tailoring these interventions to specific farmer profiles, policymakers and development practitioners can more effectively support climate adaptation, reduce vulnerability, and improve livelihoods for smallholder farmers across diverse contexts.

5.5. Limitations of this study

Methodological limitations include potential biases in self-reported data from questionnaires and interviews as participants may inaccurately recall or interpret information. The limited sample size may not adequately reflect the diverse experience of smallholder farmers and market agents in KZN. The self-reported perceptions by the respondents are susceptible to recall bias or social desirability bias, especially in structured surveys. Additionally, the four-month data collection period may fail to capture seasonal variations and long-term climate impact trends, limiting the study's temporal scope. While the model does not account for the possibility of reverse causality, the researcher acknowledges this as a limitation and further recommends that future studies adopt a model that accounts for reverse causality.

5.6. Declarations

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CHAPTER 6

THE PERCEPTIONS OF CLIMATE CHANGE ON FOOD SECURITY BY THE SMALLHOLDER FARMERS, IN KWAZULU-NATAL

Merishca Naicker¹, Denver Naidoo², Mjabuliseni Simon Ngidi³

1. African Centre for Food Security (ACFS), School of Agriculture Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg 3201, South Africa.
2. Department of Agricultural Extension and Rural Resources Management, School of Agriculture Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg 3201, South Africa.

*Correspondence: ngidim@ukzn.ac.za

Abstract: This study investigates smallholder farmers' perceptions of climate change and its impact on food security in KwaZulu-Natal, South Africa. Using a mixed-methods approach, data were collected through questionnaires and focus group discussions with 200 smallholder farmers., who were purposively selected the findings revealed that 93% of the farmers were aware of climate change, identifying altered weather patterns, increased temperatures, and erratic rainfall as primary factors that adversely affect crop yields and food security. Despite widespread awareness, some farmers lack access to crucial climate information, highlighting the need for improved communication strategies. Demographic analysis shows an ageing farming population with varied educational levels, further complicating their adaptation to climate change. The study underscores the increasing frequency and severity of climate-related events, such as floods and droughts, which exacerbate the vulnerability of farmers reliant on rain-fed agriculture. Economic challenges, including rising input costs and market exploitation, hinder the adoption of effective adaptation strategies. This research emphasizes the need for targeted interventions to enhance farmers' adaptive capacity, promote sustainable agricultural practices, and ensure food security. The study concludes by advocating integrated, multi-faceted strategies involving stakeholders at various levels to build resilient agricultural systems in KwaZulu-Natal and similar regions.

Keywords: Smallholder Farmers, Food security, Climate change, Perceptions, KwaZulu-Natal

6.1. Introduction

Agriculture is a key sector in South Africa, especially in rural households, which considerably raises livelihoods and lowers food insecurity (Nodayizana & Ritter, 2022). 19.26% of jobs are generated by agriculture, with KwaZulu-Natal accounting for the second-highest share (Stats SA, 2022). Smallholder farmers play a vital role in the economy of South Africa, and their understanding of climate change is vital for the sustenance of the economy and food security status of the country (Olabanji *et al.*, 2021). The study addresses the three key pillars of food security: availability, referring to the production of food; accessibility, encompassing income levels and purchasing power.

Climate change poses a significant threat to global food security, particularly impacting smallholder farmers, who are at the forefront of agricultural production. Smallholder farmers report observable changes in weather patterns, increased temperatures, and erratic rainfall, all of which directly affect crop yields and threaten food security and economic stability within their communities. Smallholder farmers' vulnerability to climate change is exacerbated by their limited adaptive capacity (Olabanji *et al.*, 2021; Yahaya, 2023). This deficiency makes smallholder farmers highly susceptible to the adverse effects of climate change, further increasing the risk of food insecurity.

Previous research has underscored the direct link between climate change and food security, highlighting the disruptions in crop production, income generation, and food availability caused by changing weather patterns and extreme climatic events (Mugabe *et al.*, 2022; Johnson, 2024). Sustainable farming practices and the integration of climate-smart technologies have emerged as essential strategies for mitigating these effects (Odhiambo *et al.*, 2019; Workalemahu & Dawid, 2021). However, despite these advances, gaps remain in our understanding of smallholder farmers' perspectives on climate change and its implications for food security.

Studies such as Maziya (2024) have emphasized the challenges faced by smallholder farmers, including restricted access to climate change knowledge and the slow adoption of new technology. These challenges are critical to addressing whether smallholder farmers' resilience to climate change should be strengthened. Yahaya (2023) and Asare-Nuamah *et al.* (2019) highlighted the importance of sustainable agricultural practices and a deeper understanding of the factors influencing farmers' adaptation strategies to ensure long-term food security.

Further exploration of smallholder farmers' perspectives on climate change is crucial for developing effective adaptation strategies that address their specific challenges and needs. By focusing on the unique experiences and constraints of these farmers, particularly in regions such as KwaZulu-Natal, future research can inform targeted interventions that enhance the resilience of smallholder farming systems to climate change.

The proposed study is significant as it offers insightful information about how KwaZulu-Natal's smallholder farmers view climate change and how it impacts food security. While previous studies have examined smallholder farmers' vulnerability to climate change (Yahaya, 2023; Maziya, 2024), this study offers a unique focus on KwaZulu-Natal, a region that, to date, remains underexplored in terms of climate perception. This research also delves into the specific coping mechanisms farmers use to maintain food security amidst climate volatility, providing new insights into local socio-economic and ecological challenges. By building on the gaps identified in studies such as Olabanji *et al.* (2021), this study distinguishes itself by integrating perception data and practical adaptation strategies. Furthermore, by improving smallholder farmers' knowledge of food security and climate change, our research may enhance food and nutrition security outcomes in local communities. This could impact smallholder farmers' application of adaptation techniques.

Thus, the objectives of this study were to explore how smallholder farmers in KwaZulu-Natal perceive climate change and its effects on their ability to produce crops and to identify the adaptation strategies, challenges, and opportunities for these farmers, to inform the development of effective policies and interventions to support their adaptation to climate change and ensure optimal food security in the region.

6.2. Material and methods

6.2.1. Description of the Study

The study was conducted in KwaZulu-Natal, a province in South Africa. Due to their diverse landscapes, agriculture plays a vital role in KwaZulu-Natal (Kwazulu-Natal Municipalities, 2024). The province experiences an annual maximum temperature of 24.77 °C and a minimum temperature of 19.7 °C. Every year, 106.56 millimetres of precipitation falls on average (Kwazulu-Natal Municipalities, 2024). Agriculture is one of the primary industries in rural areas of the province that provides jobs. The three primary economic sectors of the province are agriculture, tourism, and industry (STATS SA, 2022).

The area was chosen because of the recent extreme weather event that deteriorated agricultural production in the area. By understanding the perceptions of climate change and food security

of the surveyed smallholder farmers, insight will be gained into how it affects their production. The study area covered all 11 districts of KwaZulu-Natal as seen in Figure 6-1 below. The native language spoken is IsiZulu (Kwazulu-Natal Municipalities, 2024). The most common vegetables grown by smallholder farmers are spinach, cabbage, dry beans, green beans, imbuwe, and brinjal (STATS SA, 2022).

The province had experienced extreme weather events such as flooding, which was worsened by looting in 2021 and the effects of the COVID-19 pandemic (Grab & Nash, 2023). KwaZulu-Natal sheds light on various aspects of agriculture, ranging from governance and institutional factors to soil fertility constraints, climate change impacts, and expenditure patterns (Grab & Nash, 2023). Understanding these dynamics is essential for sustainable agricultural development in the region.



Figure 6- 1: Map of study location used in the study.

6.2.2. Research design

To comprehensively examine how smallholder vegetable farmers in KwaZulu-Natal perceived the impact of climate change on food security, this study utilized a mixed-methods approach integrating qualitative and quantitative data to offer a more nuanced understanding of smallholder farmers' perceptions. The study, which took place over four months, from December 2023 to March 2024, employed quantitative and qualitative methods to thoroughly investigate how smallholder farmers viewed the impact of climate change on food security.

The qualitative component involved focused discussions with 12 groups of ten smallholder farmers, each of whom was chosen because of their significant responsibilities in the

province's agricultural industry. The in-person semi-structured interviews were conducted at convenient locations for the participants. The interview guide was designed to explore the functions and procedures in the agricultural industry, the difficulties faced, and possible avenues for development. With the participants' permission, all interviews were audio-recorded, and the transcripts were verbatim for a thorough thematic analysis (Omar *et al.*, 2020).

In addition to this, the study's quantitative component consisted of distributing a structured questionnaire to 200 smallholder farmers who were purposefully selected as a sample. These farmers were selected based on their membership in regional agricultural associations and their active involvement in vegetable production. The purpose of the questionnaire was to gather vital information about farmers' perceptions of climate change, farming methods, demography, and their food security status and perceptions of the impacts of climate change on food security. The survey enabled respondents to provide comprehensive insights into their experiences while also facilitating statistical analysis, thanks to its combination of closed- and open-ended questions (Farina & Pepe, 2022).

The synthesis of both quantitative and qualitative data facilitated an all-encompassing study, augmenting the profitability and dependability of the conclusions. While qualitative data were examined thematically to gain a deeper understanding of climate and food security, quantitative data were examined using descriptive statistics to find important patterns and linkages. The triangulation of data made possible by this mixed-methods approach ensured a comprehensive grasp of the intricacies of perceptions of climate change on food security (Grant, 2023).

6.2.3. Sampling procedure and sample size

To select participants who had employment directly in the region's agricultural sector, this study adopted a purposive sampling methodology. This method allows researchers to focus on participants who possess the traits or life experiences most pertinent to the study (Whitehead, 2021). This study utilized a purposive sampling approach, selecting participants who are actively engaged in vegetable production and directly impacted by climate change in KwaZulu-Natal. A total of **200 smallholder farmers** were selected, drawn from all 11 districts of the province. A 95% confidence interval and a 5% margin of error were applied. This sampling method is appreciated for its simplicity and impartiality, providing each member of

the population with an equal chance of selection (Asrial *et al.*, 2022). It is particularly effective for producing results that can be generalized to the wider population (Tanaka & Miki, 2022).

Farmers were identified through local agricultural extension offices and market directories, ensuring that participants were representative of various agro-ecological zones and farming practices in the region. Although this approach may have excluded unregistered farmers, those registered share similar characteristics (Beharielal *et al.*, 2022). Key informants from regional agricultural associations and community leaders assisted in identifying eligible participants based on their extensive involvement in farming and their exposure to climate impacts.

In addition to the farmer selection, 12 focus group discussions were conducted with ten smallholder farmers per group, selected from the same sampling frame. These discussions provided in-depth qualitative insights into the farmers' perceptions of climate change and adaptation strategies. This mixed-methods design allowed for both breadths, through the survey of 200 farmers, and depth, through the focused discussions. The purposive sampling method ensured that participants were those most knowledgeable and directly affected by climate change, enhancing the study's relevance and practical implications.

Based on their roles and experience in the region's agricultural industry, smallholder vegetable farmers comprised the sample population for the questionnaire survey and focus group discussions. Smallholder vegetable producers in KwaZulu-Natal, who were registered with regional agricultural organizations, provided a sample frame with an in-depth understanding of the region's agricultural environment and possible participants (Yanan, 2024). To ensure thorough representation, lists of registered farmers were gathered from regional agricultural offices and market directories (Salunke, 2024).

Using a semi-structured interview guide specifically designed to examine the issues faced by smallholder farmers, their perspectives on climate change, and the region's food security, focus group discussions were held in person (Jefrydin *et al.*, 2019). With the participants' permission, audio recordings of every interview were made at convenient places. Following a comprehensive investigation, the tapes were transcribed verbatim (Farina & Pepe, 2022).

To ensure the validity and reliability of the perception data collected in this study, a multi-step approach was employed. The perception of climate change was initially assessed through two core questions focused on participants' recognition of changing climatic patterns and their perceived impact on agricultural productivity. These questions were derived from previously validated instruments used in similar contexts (Asare-Nuamah *et al.*, 2019; Olabanji *et al.*, 2021; Yahaya, 2023), ensuring construct validity. To enhance content validity, the

questionnaire was reviewed by agricultural extension officers familiar with the local farming communities and adjusted to reflect regional dialects and farming realities in KwaZulu-Natal.

To strengthen reliability, a pilot test was conducted with 15 smallholder farmers outside the main study areas. Feedback from the pilot informed minor revisions to ensure clarity, consistency in interpretation, and cultural appropriateness. Additionally, internal consistency of the perception-related items was evaluated using Cronbach's alpha, yielding a value of 0.78, which is within the acceptable range for social science research (Taber, 2018).

Further validation was achieved through triangulation with qualitative data obtained from twelve focus group discussions. These discussions provided depth to the perception constructs and supported the interpretation of quantitative responses, thus minimizing response bias and enhancing data trustworthiness. The methodological rigor adopted in this study ensures that the perception measures accurately reflect smallholder farmers' views on climate change and its effects on food security.

6.2.4. Data analysis

This study utilized a methodical approach to data analysis, incorporating both quantitative and qualitative techniques to attain a thorough comprehension of the perspectives of smallholder vegetable farmers in KwaZulu-Natal regarding the impact of climate change on food security.

Descriptive statistical techniques were used to evaluate the quantitative data collected from structured questionnaires. This analysis aimed to provide an overview of the main traits of the sample respondents, including their farming techniques, views on climate change, and perceptions of food security. The data were examined for patterns and trends using descriptive statistics such as means, frequencies, and percentages. Furthermore, cross-tabulations were carried out to examine correlations between other variables, including whether opinions on climate affect the state of food security. Statistical analysis was performed using SPSS software (version 27).

The food security assessment utilized the internationally recognized food measurement tool, the Household Food Insecurity Access Scale (HFIAS). The perception of food security was indirectly assessed using self-reported experiences captured through the HFIAS. This scale was employed to evaluate the "access component of household food insecurity," based on data provided for one month (Coates *et al.*, 2015). The HFIAS consists of nine questions focused on an individual's uncertainty and anxiety about food access, as well as the quantity and quality of food consumed by a household. The primary goal of the survey was to assess whether

participants had experienced challenges in accessing food over the past 30 days. Participants were asked to indicate how often each situation occurred, with options ranging from "rarely or never" (once or twice in the past month), "sometimes" (three to ten times in the past month), or "often" (more than ten times in the past month). The HFIAS was embedded within the structured questionnaire administered to farmers and served as a proxy measure for food security perception. By relying on participants' lived experiences and subjective evaluations, this method provided valuable insight into how smallholder farmers perceive and experience food-related challenges under conditions of climate variability.

Thematic analysis method for identifying, analysing, and reporting patterns within qualitative data was employed to interpret data obtained from focus group discussions (Kurniawati & Huda, 2021). Transcripts of the discussions were meticulously reviewed and coded to extract recurring themes related to participants' perceptions of climate change, food security status, challenges encountered by smallholder farmers, and suggested strategies for improvement

An inductive, iterative coding process was adopted, allowing themes to evolve and be refined as the analysis progressed. This flexible approach enabled the emergence of nuanced insights that closely reflected participants' lived experiences. The qualitative data was managed and organized using NVivo version 12, which facilitated the systematic exploration and categorization of complex themes.

The qualitative findings were integrated with quantitative data through triangulation, a methodological strategy that enhances the validity and reliability of research by comparing and corroborating results from multiple sources (Kurniawati & Huda, 2021). This mixed-methods integration enabled a deeper understanding of the multifaceted issues affecting smallholder farmers, particularly the interrelationships between climate change impacts, food security dimensions (availability, accessibility, and utilization), and adaptive practices. The triangulation not only validated the findings but also enriched the interpretation by contextualizing statistical trends with experiential narratives

6.2.5. Ethical Considerations

Ethical approval for this study was obtained from the Human and Social Sciences Research Ethics Committee (HSSREC). Written informed consent was obtained from all participants, ensuring that they were fully informed about the study's purpose, procedures, and rights, including the right to withdraw at any time. The Department of Agriculture provided a gatekeeper's letter, which was needed to access smallholder farmers' data in KwaZulu-Natal.

Participants' confidentiality and anonymity were maintained throughout the study. Data were securely stored and accessible to the research team.

6.3. Findings and Discussion

6.3.1. Socioeconomics and distribution of farm characteristics

Understanding the demographic profile of smallholder farmers is essential to interpreting their perceptions of climate change and its effects on food security. This section presents the socio-economic and household characteristics of the 200 respondents from KwaZulu-Natal who participated in the study, including insights from 12 focus group discussions. Participants were purposively selected with assistance from local extension officers and market agents to ensure a representative sample of actively engaged smallholder farmers.

As shown in Figure 6-2, participant ages range from 26 to 83 years, with a mean age of 49. This age distribution is consistent with findings by Molotsi *et al.* (2019), who highlight the ageing nature of South Africa's smallholder farming population, which can have implications for adaptation to climate change. Older farmers may have extensive experience in farming yet may also be less receptive to new technologies or adaptation strategies, thereby impacting their ability to respond effectively to climate variability (Bryan *et al.*, 2009; Deressa *et al.*, 2011).

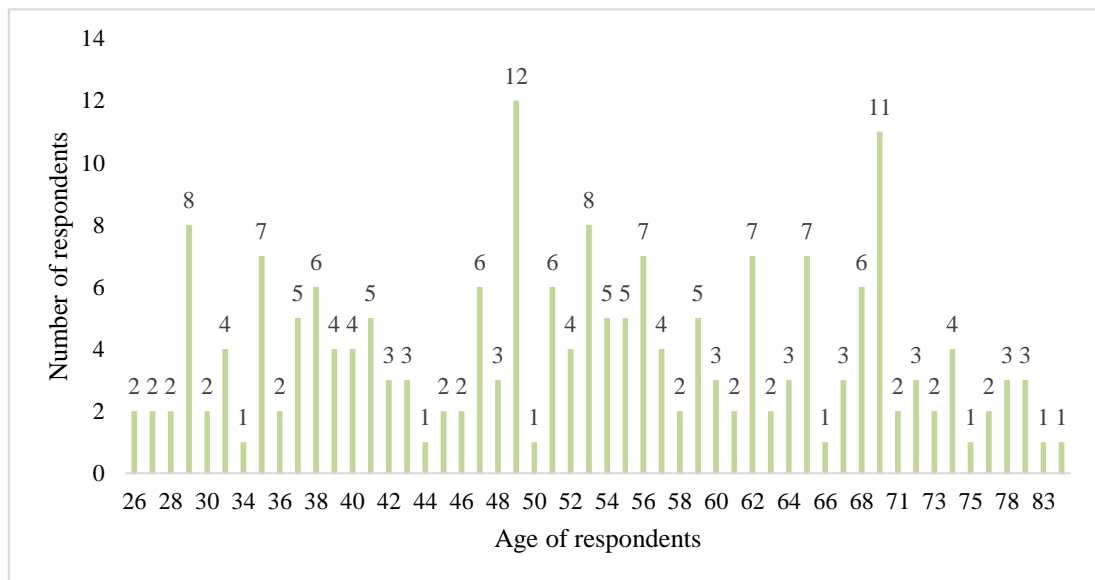


Figure 6- 2: Age of the respondents surveyed.

As shown in Table 6-1, the majority of respondents (52.5%) were married, followed by (26%) who were single, (12%) widowed, and (9.5%) divorced. Educational attainment varied, with most participants (50.5%) having completed secondary education, (18.5%) possessing tertiary

qualifications or higher, and only (6%) reporting no formal schooling. These findings contradict Zondi *et al.* (2022), who argue that smallholder farmers in South Africa are predominantly illiterate, older, and lack access to market information.

Table 6-1 also indicates that (66.5%) of respondents were household heads, (15%) were spouses of household heads, and the remainder were other family members, including siblings and children. Household sizes ranged from one to 14 members, with (37.5%) of households comprising three to four members, and (26.5%) consisting of one to two members. Household size plays a significant role in food security, with larger households often experiencing greater food insecurity due to increased resource demands and financial pressures (Nkomoki *et al.*, 2019; Biam & Tavershima, 2020; Hlatshwayo *et al.*, 2023).

Table 6- 1: Demographics of the Smallholder Farmers.

Variable		Frequency (n=200)	Percentage (%)
Marital Status	Single	52	26
	Married	105	52.5
	Divorced	19	9.5
	Widowed	24	12
Education level of respondents	No Formal Education	12	6
	Primary	50	25
	Secondary	101	50.5
	Tertiary & above	37	18.5
Position in the Household	Household Head	133	66.5
	Spouse to household head	30	15.0
	Sister	5	2.5
	Brother	4	2.0
	Daughter	8	4.0
	Son	19	9.5
	Mother	1	0.5
Household Size	1-2	53	26.5
	3-4	75	37.5
	5-6	37	18.5
	7-8	14	7
	9-10	11	5.5
	11-12	8	4
	13-14	2	1

Table 6-2 shows that (85%) of respondents rely mainly on farming for income, while (15%) depend on other sources such as state grants, pensions, or employment. This highlights the community's economic reliance on agriculture and the vulnerability of smallholder farmers to

climate-related disruptions. Although some financial resilience exists among those with alternative incomes, the findings emphasize the need for targeted support to build climate resilience, diversify income sources, and enhance the stability of farming livelihoods (Asare-Nuamah *et al.*, 2019; Yahaya, 2023).

Table 6- 2: Main income source of the surveyed participants.

Is farming the main source of income?	Percentage of Participants (%)
Yes	85
No	15

6.3.2. Perceptions by smallholder farmers on climate change

Understanding how climate change farmers can make informed decisions regarding crop production. The majority (93%) of the respondents indicated that they understood what climate change was, (3.5%) didn't understand, and (3.5%) said that they did not know what climate change was, as illustrated in Table 6-3. Smallholder farmers in South Africa play a crucial role in the country's agricultural sector by contributing significantly to food production and rural livelihoods. Given the increasing challenges posed by climate change, smallholder farmers need to understand the implications of climate change on farming practices and livelihoods. Climate change is expected to have diverse impacts on agriculture, including changes in temperature, precipitation patterns, and the frequency of extreme weather events, all of which can significantly affect crop yield, water availability, and overall farm productivity (Kom *et al.*, 2019). As per the focused group discussions, the responses highlight a multi-faceted understanding of climate change, describing it as a significant alteration in seasons, weather patterns, and rainfall, with notable temperature increases observed, particularly in the past decade. These changes are primarily attributed to human activities, including deforestation, vehicle emissions, modernization, and emissions from cattle farming (Brenner, 2019). Global warming and the depletion of the ozone layer have also been cited as contributing factors. The consequences of these changes include sporadic and severe weather phenomena, such as flash floods and heavy winds, as well as hotter weather (Zhang *et al.*, 2021). Additionally, some elderly participants perceived these changes as divine retribution, and there is a historical context in which ozone layer depletion is neglected (Milovanoff *et al.*, 2022).

Table 6- 3: Respondents’ understanding of climate change.

Do they understand what climate change is?	Percentage of Participants (%)
Yes	93
No	3.5
Don’t know	3.5

The data identified that (82%) of the respondents stated that they received information about climate change and (4.5%) didn’t know, (13.5%) didn’t receive any information about climate change. The main source of information on climate change was the television, as reported by 72% of the population, followed by the Internet (60.5%), and the radio (48%), as demonstrated in Figure 6-3. Understanding and obtaining information on climate change is vital for smallholder farmers in South Africa because it enables them to recognize the signs and impacts of changing weather patterns on their agricultural activities. By being aware of climate change phenomena such as shifting rainfall patterns, prolonged droughts, and increased temperatures, farmers can proactively implement adaptation strategies to mitigate potential risks and safeguard their crops and livelihoods (Woldeselassie *et al.*, 2021). This knowledge empowers farmers to make informed decisions regarding crop selection, planting times, water management practices, and other agricultural activities, which can help them adapt to changing climatic conditions (Zikhali *et al.*, 2021).

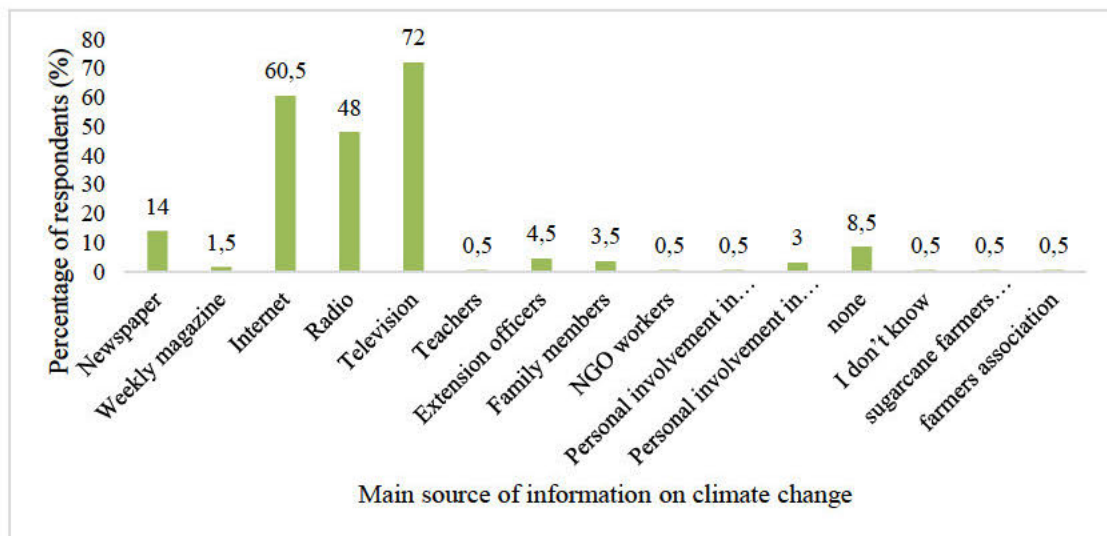


Figure 6- 3: Respondents' main source of information on climate change.

The respondents reported that the main cause of climate change is deforestation (69.5%), followed by livestock emissions (63%), and land clearing for farming (59%), these minority (0.5%) said urbanisation, vehicle emission, humans and firms were the main cause and reason for climate change as shown in Figure 6-4. The primary causes and reasons for climate change

experienced by smallholder farmers in South Africa stem from a combination of factors, including extreme weather events, limited resources for adaptation, dependence on rain-fed agriculture, water scarcity, and socioeconomic vulnerabilities (Naazie *et al.*, 2023). Addressing these challenges requires targeted interventions that enhance the adaptive capacity of smallholder farmers, promote sustainable agricultural practices, improve access to resources and support services, and build resilience to climate change impacts in the agricultural sector (Olabanji *et al.*, 2021).

Access to information plays a critical role in shaping smallholder farmers' perceptions of climate change and influences their adaptive capacity and resilience. Respondents who received information from formal sources such as agricultural extension officers, local NGOs, or government agencies were more likely to see climate change as a long-term, systemic trend rather than as isolated or random weather variations. This aligns with findings from Deressa *et al.* (2011) and Mersha & van Laerhoven (2016), who assert that credible and continuous information provision enhances farmers' understanding of climate patterns and encourages the adoption of appropriate adaptation strategies.

Farmers exposed to structured climate-related information tend to have greater awareness of the causes and consequences of climate change, enabling them to make informed decisions regarding crop choices, planting times, water management, and other critical agricultural practices. This informed perspective fosters proactive adaptation rather than reactive coping mechanisms, contributing to enhanced household resilience (Niles *et al.*, 2015). In contrast, farmers with limited access to such information often rely on traditional knowledge or experiential observations, which may not fully capture the evolving and complex nature of climate variability.

Moreover, access to information often correlates with improved access to resources such as training, financial support, and technological innovations, factors that collectively strengthen adaptive capacity (Below *et al.*, 2012). Therefore, integrating information dissemination into agricultural development programs is essential to empower smallholder farmers, improve their risk perception, and support sustainable adaptation strategies in the face of climate change.

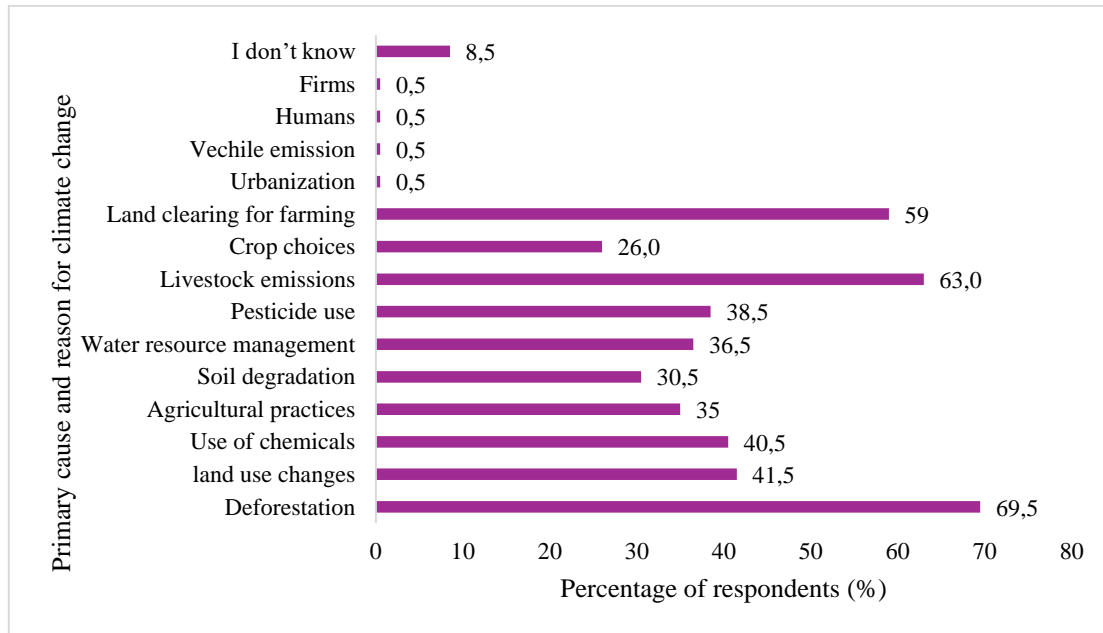


Figure 6- 4: The primary cause and reason for climate change by the surveyed population.

The data showed that (85.5%) of the respondents indicated that climate change has occurred in their region, (3.5%) said it didn't occur, (11%) were uncertain. As seen in Table 6-4 below (81.5%) of the respondents had said that frequent flooding was the main type of climate change that occurred in their region, followed by excessive temperatures (76%) and changes in rainfall patterns by (66.5%). The types of climate change that occur in South Africa include rising temperatures, changing precipitation patterns, extreme weather events, sea-level rise, and impacts on biodiversity and agriculture. Addressing these climate change challenges requires a multi-faceted approach that integrates mitigation efforts, adaptation strategies, and sustainable development practices to build resilience and foster climate-resilient communities in South Africa (Guo *et al.*, 2019). The discussions from the focus groups emphasized that climate change has brought about significant challenges for agricultural communities across the region. Open-field farmers have been particularly devastated by recurring floods since 2021, which have destroyed crops, irrigation systems, and essential equipment, aggravating food shortages and driving up prices. Unpredictable heatwaves further impair crop growth (Reyes *et al.*, 2021). Dryland farmers face their struggles due to erratic rainfall patterns that disrupt crop cycles and reduce yields. Temperature fluctuations have necessitated changes in traditional crop choices, with previously viable crops, such as tomatoes, becoming less reliable (Hefele, 2020). Water scarcity during critical planting seasons has forced farmers to reconsider what crops to grow and abandon those that require abundant water, such as dhanias. Moreover, the emergence of new pests and diseases has worsened crop health and productivity by

increasing the use of fertilizers (Li *et al.*, 2022). These compounding environmental pressures underscore the urgent need for adaptive strategies and support mechanisms to sustain agriculture in the face of ongoing climate change challenges. Extreme weather events, such as droughts, floods, and storms, are becoming more frequent and intense in South Africa owing to climate change (Workalemahu & Dawid, 2021). These events can have devastating effects on communities, infrastructure, and natural ecosystems. Smallholder farmers often bear the brunt of extreme weather events, such as crop losses, soil erosion, and disruptions to their farming activities, highlighting the urgent need for climate-resilient agricultural practices.

Table 6- 4: The types of climate change that have occurred in the region.

Types of climate change occurred in the region	Percentage of Participants (%)
Excessive temperatures	76
Excessive cold	24
Change in rainfall pattern	66.5
Frequent floods	81.5
Waterlogging	35
Don't know/ don't understand	12.5

As captured (66.5%) of the surveyed population believed something could be done about climate change and (7.5%) said nothing can be done, whilst (26%) don't know. Climate change was seen to be very important to (80%) of the surveyed population, as depicted in Figure 6-5, and (6%) of the respondents said that climate change was not important at all. A key reason for the importance of climate change is its significant impact on agriculture, as emphasized in studies focusing on the major crops in Eastern Africa (Acevedo *et al.*, 2020). Changes in temperature and precipitation patterns due to climate change can result in heat and water

stresses, which can limit crop yields and jeopardize food security, particularly affecting smallholder farmers who depend heavily on agriculture for their livelihoods (Hefele, 2020).

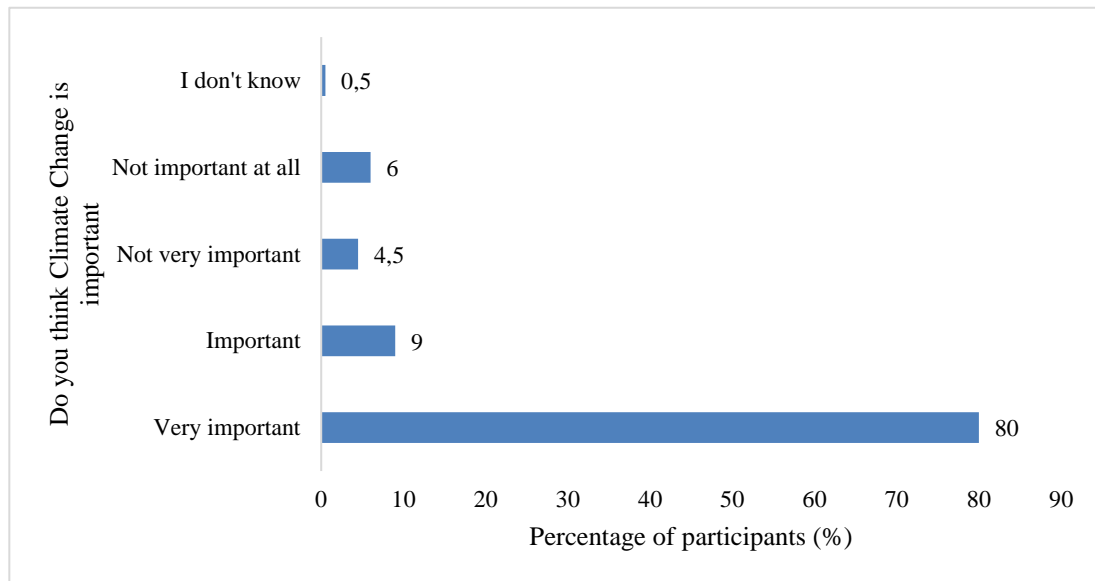


Figure 6- 5: Respondents’ perception of the importance of climate change.

Figure 6-6 illustrates the frequency of the various challenges faced by the respondents in the agricultural sector. The x-axis represents different issues, such as recurrent floods, droughts, crop diseases, crop failure (other than from drought), price decline for produce, soil fertility decline, price increase for inputs, shorter rainy seasons, late onset of rain, and climate variability. The y-axis shows the percentage of respondents experiencing these issues, categorized by frequency: never (0 times), Rarely (1-2 times), Sometimes (3-4 times), and often (>4 times).

The data reveals that "Often (>4 times)" is the most common frequency for most challenges, particularly for recurrent droughts, price increases for inputs, and climate variability, each affecting around 70% of respondents. In contrast, recurrent floods and crop diseases are less frequently experienced, with "Never (0 times)" and "Rarely (1-2 times)" being more common responses. This suggests that, while certain issues such as drought and input prices are persistent and widespread, others such as flooding and disease are less prevalent or impactful within the surveyed population. Research has underscored smallholder farmers’ extreme vulnerability to agricultural risks and climate change, highlighting the lack of comprehensive information on their vulnerability and adaptation requirements (Asare-Nuamah *et al.*, 2019).

Smallholder farmers, mainly in developing countries, are projected to bear the brunt of global climate change impacts, which can have profound effects on their livelihoods and agricultural practices (Workalemahu & Dawid, 2021). The impact of climate change on smallholder

farmers' productivity, production costs, and financial constraints on their livelihoods is exacerbated by climate change, which impacts their sustainability and growth (Gumbi, 2023).

The focused group discussions highlighted that farmers are grappling with the severe challenges posed by climate change and the unpredictability of nature, which has made farming increasingly difficult, especially over the past five years. Many farmers feel powerless against these elements, leading to significant crop losses and difficulties in managing their farms. While some are trying to adapt through various methods, such as changing crop types, irrigating strategically, and using fertilizers and chemicals, these measures often fall short. Economic constraints further exacerbate the situation, as rising costs of seeds and chemicals and dropping profit margins hinder their ability to implement the necessary changes. Despite these efforts and challenges, many farmers continue to seek alternative income sources and ways to mitigate these issues; however, the struggle remains substantial. As per, Cheng *et al.* (2023) intensification of weather extremes, including an increase in the frequency and severity of extreme weather events, is a significant facet of climate change and affects agricultural production negatively.

Farmers need to recognize their challenges so that they can find ways to overcome and mitigate them. Furthermore, the impact of climate change on smallholder farmers extends beyond agricultural productivity to economic losses, disruptions in livelihoods, and climate-induced constraints, highlighting the importance of risk-transfer policies and adaptation strategies to safeguard their welfare (Choquette-Levy *et al.*, 2021). Providing education and training to smallholder farmers on climate change and plant pathology is essential to promote resilience and sustainable farming practices in the face of changing climatic conditions (Kom *et al.*, 2019).

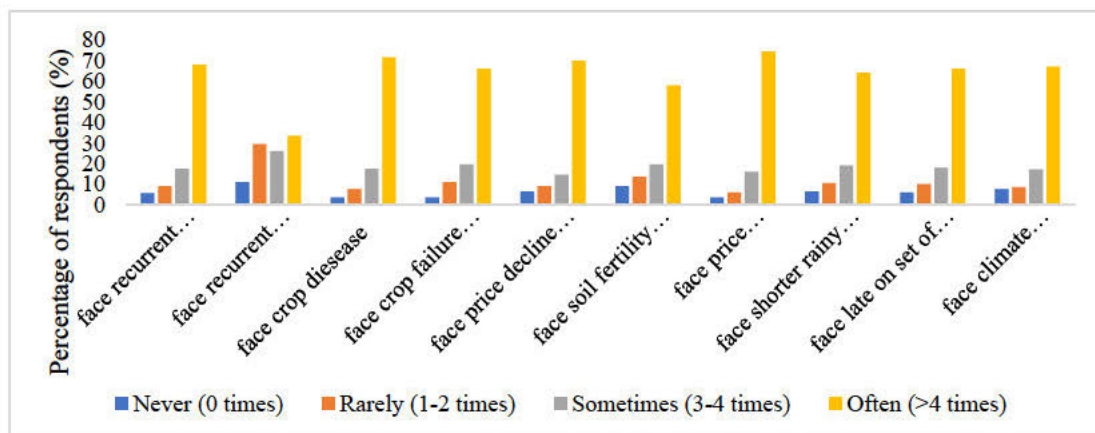


Figure 6- 6: Respondents' concerns about the likelihood of climate events affecting their households.

6.3.3. Impact of climate change on food security

Respondents' perceptions of the impact of climate change on various aspects of food security are depicted in Figure 6-7. The x-axis specifies the percentage of respondents, while the y-axis lists the different impacts of climate change on food security. The responses were categorized into six levels of agreement ranging from strongly Agree to Do Not Know.

A majority of respondents "Agree" or "Strongly Agree" that climate change leads to a scarcity of food (70.5% and 17%, respectively) and an increase in food prices (79.5% and 12%). Likewise, reduced income was also strongly perceived as an impact, with 71% agreeing and 12% strongly agreeing. Conversely, most respondents "Disagree" or "Strongly Disagree" with the statements that climate change resulted in increased employment (57.5% disagree and 8.5% Strongly Disagree) and decreased food prices (66.5% disagree and 4.5% strongly disagree). Responses for a lack of local markets and decreased employment show a mixed distribution, indicating varied perceptions (Chimombo *et al.*, 2022). The data highlight significant concerns about climate change exacerbating food scarcity, reducing incomes, and increasing food prices in the surveyed population. The farmers highlighted in the focused group discussions that they expressed a critical need for government intervention to prevent a looming food security crisis. As noted by Daniell and Tonder (2023), several factors highlight the urgent need for government action to avert an impending crisis in South Africa's food security. South Africa's crop yields are predicted to decline because of climate change, directly affecting food security and livelihoods. Many emphasize that without substantial financial support to cover the escalating costs of wages, fuel, seeds, and chemicals, established and experienced farmers will continue to face severe challenges. Smallholder farmers, especially in developing nations, face increasing vulnerability due to climate change, leading to significant challenges and rising costs related to agricultural production (Myeya, 2021).

The impact of recent looting, floods, and climate change has further strained their ability to produce enough vegetables, and without government grants and subsidies, the situation will likely worsen. In addition, some farmers are concerned about the role of middlemen, who profit disproportionately from the produce, buy at low prices, and sell at much higher prices. This reduces farmers' profitability and hampers their ability to sustain business. Overall, the consensus is that significant government support is essential for stabilizing the agricultural sector and ensuring food security. According to Conglin *et al.* (2023), one major problem is the extensive network of intermediaries and traders, which drastically reduces the revenue that smallholder farmers and customers would otherwise receive.

The impact of climate change on food security in South Africa is a complex issue requiring integrated approaches, stakeholder engagement, and policy interventions to address the challenges faced by smallholder farmers and vulnerable communities (Asare-Nuamah *et al.*, 2019). Enhancing resilience, promoting sustainable agriculture, and supporting adaptation measures are essential for ensuring food security, reducing vulnerability to climate change, and building sustainable food systems in the face of a changing climate (Maltou & Bahta, 2019)

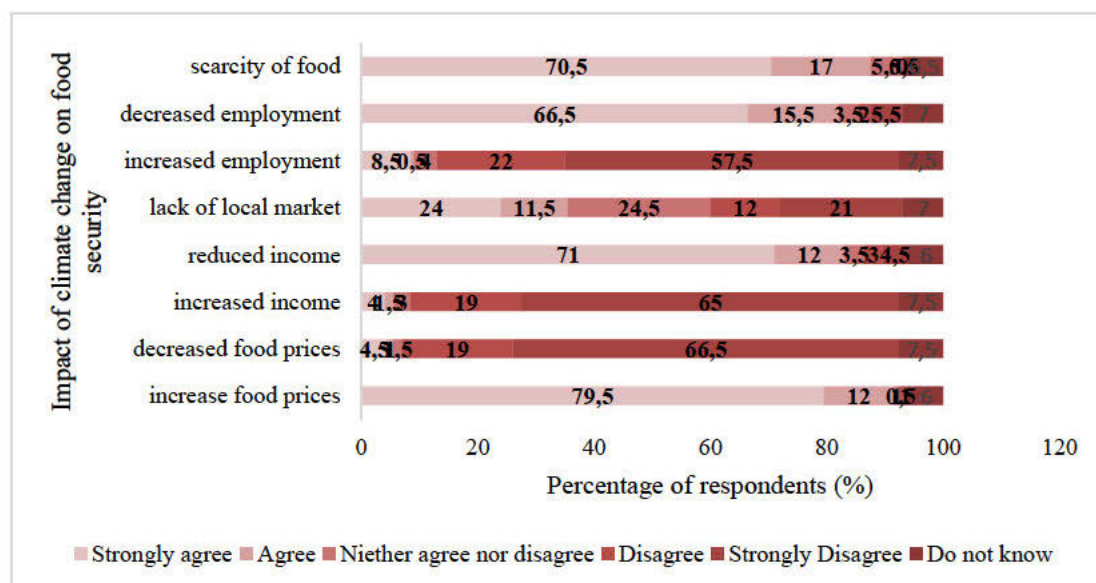


Figure 6- 7: The impact of climate change on food security for the respondents.

The Household Food Insecurity Access Scale (HFIAS) serves as a valuable tool for assessing food insecurity levels in households, measuring access to adequate food supply, and identifying vulnerable populations. Its widespread use in research studies across various countries underscores its importance in understanding and addressing global food insecurity challenges. It categorizes responses into four categories: severely food insecure, moderately food insecure, mildly food insecure, and food secure (Horwood *et al.*, 2020; Omotoso, 2023).

As shown in Table 6-5 below, (69.5%) of the respondents were food secure. Despite increasing climate pressures, the majority of the surveyed smallholder farmer households in KwaZulu Natal (KZN) remain food secure due to consumption of their produce, and their engagement in diverse livelihood strategies, improved market linkages, and access to non-farm income sources. These households often exhibit greater livelihood diversification, including small-scale trading, remittances, or social grants, which buffer against agricultural shocks (Ngcobo *et al.*, 2021). This acts as a protective factor among the food secure households. Additionally,

better connectivity to local markets enables more stable income flows and access to food, even when on-farm production is compromised. Households with stronger social networks and access to information also demonstrate higher adaptive capacity, allowing them to adjust practices in response to climatic variability (Shisanya & Mafongoya, 2020). This multifaceted resilience helps sustain food security under changing environmental conditions. (8.5%) were found to be mildly food insecure, (13%) were moderately food insecure, and (9%) were severely food insecure. The Household Food Insecurity Access Scale (HFIAS) serves as a valuable tool to assess food insecurity levels, understand coping strategies, and unravel the complex dynamics of food access in South Africa. Studies utilizing the HFIAS have provided critical insights into the prevalence of food insecurity, its determinants, and its impact on various population groups, contributing to the development of targeted interventions to address food insecurity challenges in the country (Owoputi *et al.*, 2022; Cele, 2024).

The finding that 69.5% of households in the study were classified as food secure, based on the Household Food Insecurity Access Scale (HFIAS) as seen in Table 6.5 below, initially appears inconsistent with the preceding narrative of vulnerability, marked by reduced yields, increased pest infestations, and rising input costs. However, this apparent contradiction can be reconciled by exploring a range of resilience mechanisms employed by rural smallholder households. These mechanisms help to buffer the effects of climate stressors and sustain food access, even if temporarily or unevenly distributed across the population.

Livelihood Diversification emerges as a significant contributor to household resilience. Households that combine agricultural activities with informal employment, small-scale trading, or remittances from family members working tend to be more insulated from climate-induced income volatility (Béné *et al.*, 2016; Musafili *et al.*, 2022). Diversification reduces dependency on rain-fed agriculture and allows households to smooth consumption during poor harvests, thereby maintaining food security.

Market Connectivity also plays a critical role. Households located closer to local markets or with better access to transportation infrastructure are better able to supplement food needs through purchases when own production fails. Improved market access not only enhances food availability but also enables farmers to sell produce and generate income, further contributing to food security (Tadesse *et al.*, 2018; Gebre & Rahut, 2022). In this study, food-secure households were disproportionately situated in peri-urban or more accessible rural areas, suggesting that geography and infrastructure are key mediators of resilience.

Another factor is social capital, particularly informal support networks. Participation in savings groups, community lending schemes, and reciprocal labour arrangements was reported

by some respondents and have been widely recognised in the literature as critical informal safety nets (Ellis & Freeman, 2019; Twongyirwe *et al.*, 2021). These networks enable resource-sharing during periods of food stress, helping households absorb short-term shocks without descending into food insecurity.

Though less common, the adoption of climate-resilient agricultural practices, such as the use of drought-tolerant seed varieties, mulching, and small-scale irrigation, was reported among some of the food-secure households. These practices are increasingly promoted as pathways to enhance adaptive capacity in the face of climatic uncertainty (Sapkota *et al.*, 2020; Nhamo *et al.*, 2021). While uptake remains limited due to constraints like cost and information access, their contribution to yield stability in adverse seasons was evident in a few cases.

Finally, non-farm income sources appear to distinguish food-secure households from more vulnerable ones. Off-farm income reduces reliance on agriculture and provides a more stable income stream, especially when farming becomes unviable due to climatic stress (Díaz *et al.*, 2018; Antwi-Agyei *et al.*, 2022). This aligns with broader research across sub-Saharan Africa, which finds that households with diversified income portfolios are more likely to achieve year-round food security.

Taken together, these findings suggest that food security within smallholder systems is highly differentiated and dynamic. The presence of resilience-enhancing factors, rather than the absence of climate stress, largely determines a household’s ability to maintain food access. While the current results underscore a surprisingly high level of food security, this should not be interpreted as permanent or stable, but rather as a fragile equilibrium that could quickly shift under more intense or prolonged climatic events. Therefore, future policy should prioritise scaling up access to non-farm income opportunities, improving rural infrastructure, strengthening informal social safety nets, and promoting low-cost climate-resilient agricultural innovations.

Table 6- 5: HFIAS of the surveyed respondents.

HFIAS	Percentage of Participants (%)
Food secure	69.5
Mildly food insecure	8.5
Moderately food insecure	13
Severely food insecure	9

The data presents a notable contrast between respondents' perceptions of the adverse impacts of climate change on food security and the actual food security status reported through the

Household Food Insecurity Access Scale (HFIAS) in Table 6-5 above. While (69.5%) of respondents were categorized as food secure, a significant proportion reported strong agreement with climate-related stressors affecting their livelihoods and food access. For example, (79.5%) strongly agreed that food prices have increased as seen in Figure 6-7 above, (71%), reported reduced income, and (70.5%), perceived food scarcity as a key consequence of climate change.

This discrepancy highlights the complexity and multifaceted nature of food security, particularly in rural smallholder contexts. Perceptions of vulnerability often reflect anticipatory stress and lived experiences of climate variability, even if immediate food access remains temporarily stable. As documented in several studies, food security is not merely a function of current consumption, but also of perceived risks, coping capacity, and future access to resources (Béné *et al.*, 2016; Antwi-Agyei *et al.*, 2022).

Despite high levels of perceived scarcity, employment loss, and rising input costs, the relatively high food security may be attributable to short-term coping strategies, such as borrowing food, relying on remittances, or temporary income diversification (Musafili *et al.*, 2022). However, this stability may be fragile and unsustainable, as food-secure households may still face hidden vulnerabilities such as poor dietary diversity, low nutritional adequacy, and limited resilience to shocks (Sibhatu & Qaim, 2018).

Importantly, the majority of respondents disagreed or strongly disagreed with statements suggesting positive outcomes, such as increased employment (57.5%) or decreased food prices (66.5%). This indicates that most households do not associate climate change with any beneficial economic or livelihood outcomes, reinforcing the idea that perceived impacts are overwhelmingly negative and could erode food security in the long run if unaddressed.

Furthermore, 24% of respondents reported a lack of access to local markets, a finding that aligns with literature on the role of infrastructure and market connectivity in mediating food access under climate stress (Gebre & Rahut, 2022). Market disconnection can limit both income-generating opportunities and access to affordable food, exacerbating the impacts of climate change.

Taken together, these findings reveal that while current food security levels may appear relatively high, perceived climate-induced pressures signal underlying structural vulnerabilities. These perceptions serve as critical early warning signs and justify the need for proactive interventions aimed at strengthening rural livelihoods, enhancing climate resilience, and addressing the non-material dimensions of food insecurity.

6.3.4. Household dynamics regarding food consumption, coping strategies

The survey indicated that (35.5%) of the respondents preferred vegetables to other foods, and (64.5%) preferred other foods. The other foods that the respondents served were meat (46.5%), chicken (17.5%), and maize meal (0.5%). The results illustrated that (39%) of the households didn't consume vegetables. As shown in Table 6-6 below (54.5%) of the respondents purchased their vegetables at the supermarket, (22.5%) consumed their produce, (15%) purchased from shops or stores, and (8%) purchased their vegetables from open markets. The reason for these outcomes could be that supermarket prices are more affordable and convenient to purchase.

Table 6- 6: Where respondents usually purchase their vegetables.

Where are vegetables usually purchased from?	Percentage of Participants (%)
Open market	8
Supermarket	54.5
Store or Shop	15
You consume your produce	22.5

The quantity of vegetables purchased per month ranged from 2-2000 kgs. (13.5%) of respondents purchased 20 and 40 kg of vegetables per month. Figure 6-8 illustrates the reasons for the vegetable consumption preferences. The graph presents a selection of preferences based on seven criteria: price, nutritional quality, taste, ease of preparation, cleanliness, colour, and origin. The first choice scored the highest in terms of price (50%) but significantly lower in other categories, indicating a strong focus on affordability. The second choice ranked the highest in taste (59%) and showed a balanced perspective on other factors. The third preference values ease of preparation (44.5%) and cleanliness (99.5%) are more highly. The fourth preference places importance on ease of preparation (30.5%) and cleanliness (29%) but scores lower in other categories. The fifth preference favoured colour (34.5%) and cleanliness (26.5%). The sixth preference emphasized colour (25.5%) and cleanliness (21%). The seventh preference again scored a high price (32%), but it was the least apprehension for other factors. The ranking revealed varying priorities, with price and ease of preparation emerging as significant factors in multiple preferences.

Vegetable consumption in South Africa is influenced by cultural, nutritional, economic, and health-related factors that shape dietary choices and preferences (Call *et al.*, 2019). Promoting vegetable consumption through awareness campaigns, nutrition education, and sustainable food production practices is essential for improving dietary quality, enhancing food security,

and supporting the overall health and well-being of individuals in South Africa (Modibedi *et al.*, 2021).

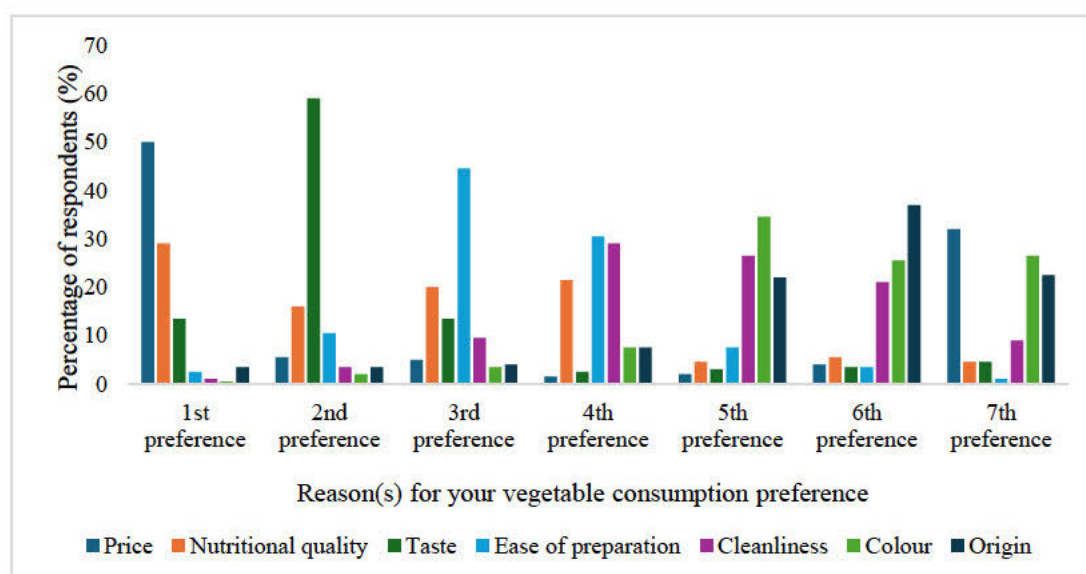


Figure 6- 8: Reasons for the respondents' vegetable consumption preference.

The triptych of histograms, Figure 6-9, illustrates the distribution of monthly spending on vegetables by respondents over three years: 2018, 2019, and 2020.

In 2018, the spending distribution was relatively widespread, with a slight decreasing trend, as indicated by the trend line. The peak spending was around the R450–R600 range. In 2019, the distribution appeared more condensed, with a notable peak around the R500-R 800 range, and the trend line showed a slight decrease. By 2020, the distribution of spending had become even more concentrated around the R600-R900 range, with a similar downward trend line indicating a general decline in the percentage of respondents spending higher amounts.

Overall, the data suggests a trend towards increased concentration in spending within a narrower range over the three years, with fewer respondents spending significantly higher or lower amounts on vegetables each month. The slight downward trends in each year may indicate stability or a slight reduction in higher spending brackets among the surveyed population.

Considering the economic context, factors such as inflation, labour costs, and government expenditure, as discussed by Tomorri *et al.* (2022) could have influenced vegetable prices during the specified period. If inflation expectations were high, labour costs increased or government expenditure rose, which might have contributed to the upward pressure on vegetable prices. Conversely, the negative impact of GDP and exchange rates on inflation

could have mitigated price increases, depending on the overall economic conditions in South Africa during 2018-2020.

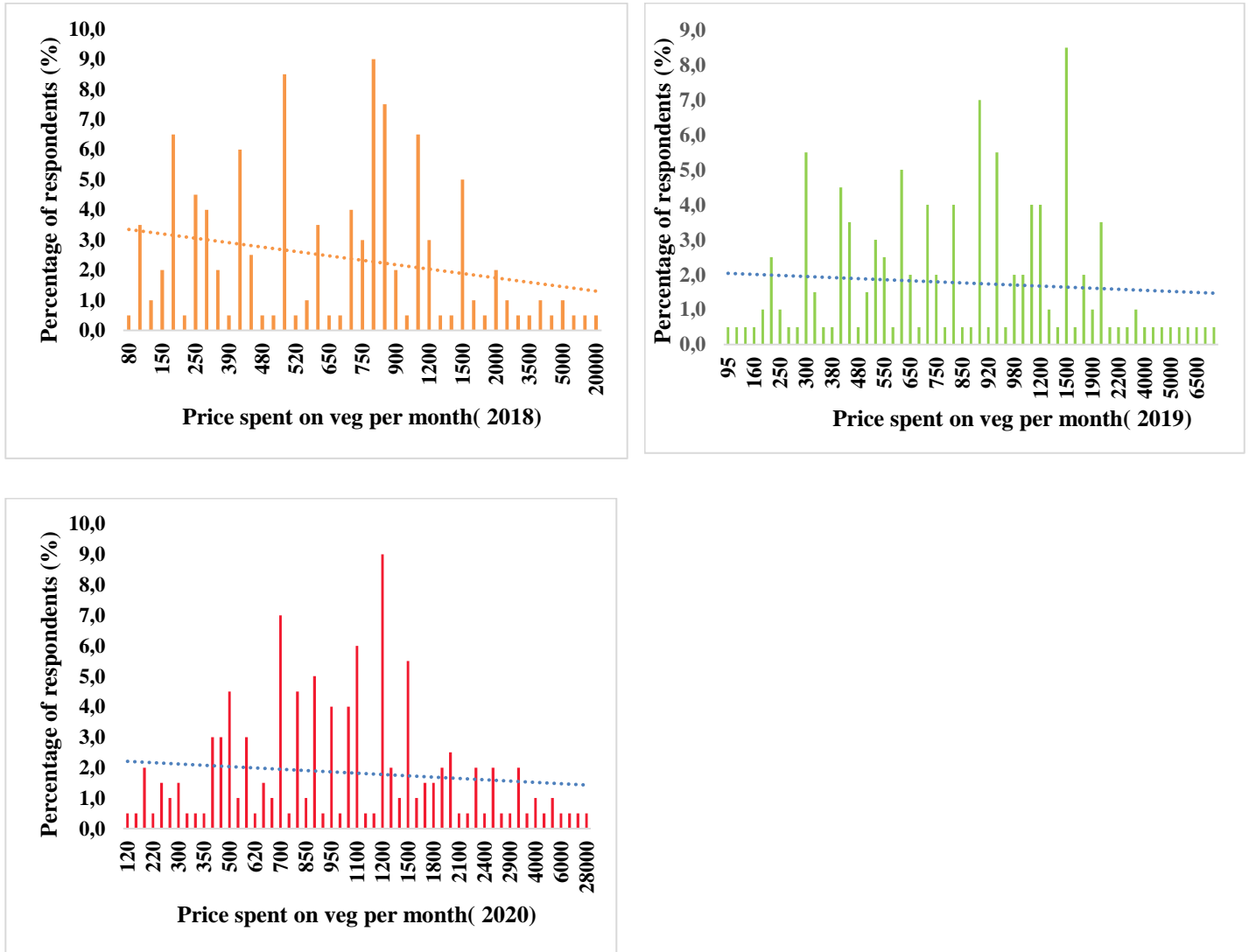


Figure 6- 9: Amount spent on purchasing veg per month for the years, 2018,2019, and 2020 by the surveyed population.

Main sources of food (78%) purchase and (22%) own produce. The number of meals consumed per day by the majority was three meals (75,5%), followed by two meals (12,5%), four meals (11,5%), and one meal (0,5%). Figure 6-10 quantifies reliance on various food security coping strategies over eight days. Initially, households predominantly relied on less preferred and less expensive food (70,5%) and sought help from friends or relatives (84,5%). As time progressed, there was a notable shift in strategies. Borrowing food or relying on help decreased sharply after day one, with minimal reliance by day three. Purchasing food on credit

was initially high (93.5%), but almost nonexistent after day one. Gathering wild food or harvesting immature crops and consuming seed stock follows a similar pattern, with high initial reliance (94% and 93%, respectively) that rapidly declines.

Sending household members to eat elsewhere or to beg, though initially considered (93.5% and 99.5%), is rarely employed beyond day one. Limiting portion sizes at meals and restricting adult consumption to prioritize children became more prominent from day five onwards, indicating increasing severity of coping mechanisms. This pattern reveals an initial reliance on immediate, less severe strategies that gradually shift to more drastic measures as the situation persists (Abdul-Rahaman & Abdulai, 2020). The farmers stressed in the focus group discussions that they are facing severe challenges due to climate change, which has drastically affected the quality and quantity of their produce. Extreme heat, unpredictable rainy seasons, and increased pests and diseases have lowered crop yields and increased costs, making it difficult to sustain the previous production levels. This statement agrees with Myeya (2021) who stated that climate change-induced factors, such as extreme weather events, shifts in precipitation patterns, and temperature fluctuations, directly influence crop yields, causing reduced productivity and increased input costs for smallholder farmers. In response, many farmers have shifted to growing crops that are easier to maintain and that require less water. However, this shift has led to an oversupply in the market, driving prices down and reducing income. The economic impact is further compounded by the high input costs, making it challenging for farmers to achieve profitability. Overall, the combination of adverse weather conditions, market saturation, and economic pressure has significantly strained the agricultural sector (Lesk *et al.*, 2022).

Households in South Africa face various challenges related to food insecurity, leading them to adopt coping strategies to mitigate the impact of inadequate food access. Dlamini *et al.* (2023) discuss coping strategies related to food insecurity in South Africa, highlighting that households resort to various measures when faced with challenges. The study revealed that a significant percentage of households rely on less preferred and less expensive foods, while a considerable proportion send a household member to beg for food (Dlamini *et al.*, 2023). Moreover, (Maia *et al.*, 2021; Gugissa *et al.*, 2022). provided insights into coping strategies adopted by food-insecure households, emphasizing changes in consumption patterns, consumption of inexpensive foods, reduction in meal frequency, and selling household assets as common coping mechanisms

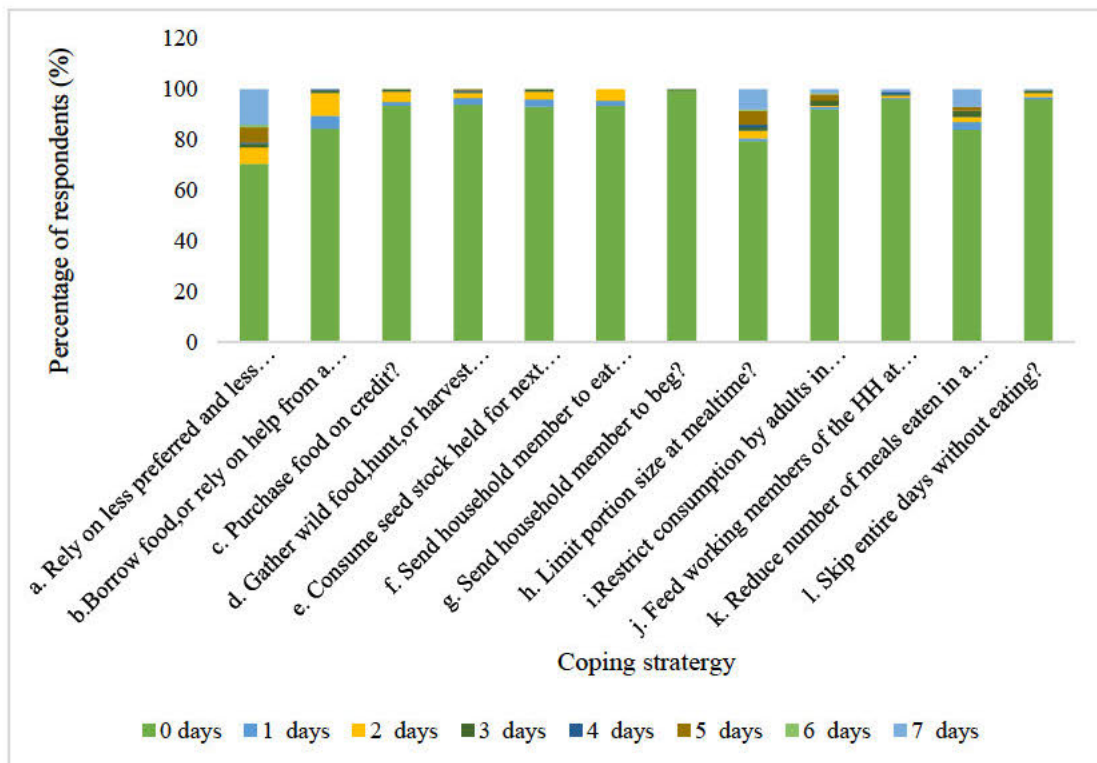


Figure 6- 10: Coping strategies of households surveyed.

6.4. Conclusion and recommendations

6.4.1 Conclusion

This study aims to gain insight into smallholder farmers' perceptions of climate change and its impact on food security in KwaZulu-Natal, South Africa, to identify inefficiencies, gaps, and areas for improvement in adaptation strategies. The findings revealed a high level of awareness among farmers regarding the effects of climate change on their agricultural activities and livelihoods, with observable changes in weather patterns, such as increased temperatures and erratic rainfall, directly affecting crop yields and threatening food security. Despite this awareness, farmers continue to face significant challenges in adapting to these changes due to economic constraints, limited access to resources, and inadequate support mechanisms.

By establishing the perceptions of smallholder farmers, this study aims to bridge knowledge gaps, strengthen resilience, and improve food security and nutrition outcomes for local populations. The study highlights the essential role of smallholder farmers in South Africa's agricultural sector, particularly in contributing to food security and rural livelihoods, and

includes participants from all 11 districts of KwaZulu-Natal, covering smallholder vegetable farmers growing crops such as spinach, cabbage, dry beans, green beans, imbuwe, and brinjals.

The research reveals several critical challenges faced by smallholder vegetable farmers in KwaZulu-Natal, especially the increasing frequency and severity of climate change-related events like floods, droughts, and unpredictable weather patterns. The reliance on rain-fed agriculture, combined with water scarcity and the socioeconomic vulnerability of smallholder farmers, poses significant risks to food production and overall food security. The data underscore a pressing need for targeted interventions that enhance adaptive capacity, promote sustainable agricultural practices, and provide adequate support to mitigate the effects of climate change.

This study also highlights the importance of educating smallholder farmers on climate change. Most respondents reported receiving information via the Internet and media, but a portion of the population still lacks access to this information, indicating a need for more comprehensive communication efforts. Ensuring that all farmers have access to the necessary information and resources to understand and adapt to climate change is essential for fostering resilience in the agricultural sector.

Economic challenges add complexity to smallholder farmers' adaptation efforts, with increasing input costs, shifting market conditions, and exploitation by middlemen making farming less profitable and adaptation more difficult. The results highlight the necessity of substantial government involvement to stabilize the agricultural sector and safeguard smallholder farmers' livelihoods, including funding, subsidies, and market regulations. Without such support, the sector's contribution to national food security may be seriously compromised.

In conclusion, this study provides new insights into the attitudes, challenges, and coping mechanisms of smallholder farmers in KwaZulu-Natal in response to climate change. The findings emphasize the necessity of integrated approaches involving stakeholders at all levels, from local communities to the government. In the face of persistent climate challenges, South Africa can better protect its food security and enhance rural livelihoods by strengthening smallholder farmers' resilience and encouraging sustainable agricultural practices.

6.4.2. Recommendations

Based on the findings, this study advocates for multi-level policy interventions involving key institutional actors aimed at enhancing smallholder farmers' resilience to climate change.

Specific recommendations include introducing subsidies for climate-resilient crops (e.g., drought-tolerant varieties of maize and sorghum), establishing decentralized rainwater harvesting systems to mitigate water scarcity, and implementing digital platforms that disseminate real-time climate information to farmers. Institutions such as the Department of Agriculture, Land Reform and Rural Development (DALRRD), local municipalities, and agricultural extension services should play a central role in facilitating these initiatives. Furthermore, collaboration with research institutions and NGOs can support the development and dissemination of locally appropriate climate-smart technologies. Training programs, particularly those tailored to older farmers, should be prioritized to improve understanding of the scientific causes of climate change and increase receptivity to adaptation strategies. By building climate-smart infrastructure and improving market access through coordinated government subsidies and institutional support, smallholder farmers in KwaZulu-Natal can better withstand the economic pressures of climate volatility

6.4.3. Implications for Further Research

Recommendations for enhancing resilience and sustainability in KwaZulu-Natal's agricultural sector present several important avenues for future research. A critical area involves assessing the long-term effectiveness of climate-resilient crops and sustainable water management practices, particularly those supported by government subsidies. Research could focus on how these interventions impact crop yields, farmer income, and overall food security. Moreover, future studies should investigate the scalability and replicability of these practices in regions facing similar climatic challenges to ensure their broader applicability.

The study also suggests that another key area for research is the effectiveness of government support and financial aid in bolstering smallholder farmers' resilience to climate change. This includes evaluating how well government initiatives reduce post-harvest losses, enhance access to climate-resilient inputs, and improve the sustainability of farming practices. Additionally, exploring the socioeconomic benefits and potential challenges associated with these programs will be crucial for informing more effective policy designs. Understanding these dynamics will help refine the strategies governments use to support agricultural resilience.

A limitation of this study is that, while it incorporated gender-sensitive insights and briefly addressed the role of markets and supply chains in shaping food access, these aspects were not explored in depth. Further research is needed to systematically examine how gender dynamics

and market integration influence household food security outcomes, particularly in the context of climate-related shocks.

Future research should consider employing regression analysis to quantitatively assess the relationship between smallholder farmers' perceptions of climate change and their food security status. This would provide a more robust statistical basis for understanding how perceived climate impacts influence food access, availability, and stability, thereby strengthening the empirical link between perception and food security outcomes.

Furthermore, this study highlights the role of education, training, and information access in climate adaptation and warrants further study. Research could explore the effectiveness of various training approaches, such as workshops, digital tools, and participatory methods, in raising awareness about climate change and promoting eco-friendly farming techniques.

Additionally, investigating how timely and accurate information influences farmers' decision-making and adaptation strategies could offer valuable insights. Complementary to this is the need to study livelihood diversification, the implementation of crop insurance, and innovative risk transfer mechanisms. These areas of research will provide a comprehensive understanding of how to create a more resilient and sustainable agricultural sector in KwaZulu-Natal and other similar regions.

6.5. Declarations

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Article

Factors Affecting the Choice and Level of Adaptation Strategies Among Smallholder Farmers in KwaZulu Natal Province

Merishca Naicker ¹, Denver Naidoo ¹, Simphiwe Innocentia Hlatshwayo ² and Mjabuliseni Simon Ngidi ^{2,3,*}

¹ African Centre for Food Security (ACFS), School of Agriculture Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg 3201, South Africa; 214504745@stu.ukzn.ac.za (M.N.)

² Department of Agricultural Extension and Rural Resources Management, School of Agriculture Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg 3201, South Africa

³ Centre for Transformative and Agricultural Food Systems (CTAFS), School of Agriculture Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg 3201, South Africa

* Correspondence: ngidim@ukzn.ac.za

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Abstract: Smallholder vegetable farmers grow diverse crops for family use and surplus sales. These farming activities contribute to enhancing local food security and the economy, but the farmers face challenges like limited resources and climate vulnerability. These smallholder farmers are more susceptible to climate variability and therefore need effective adaptation strategies to mitigate the challenges. This study sought to determine the factors that influence the choice and level of adaptation strategies among smallholder vegetable farmers in KwaZulu Natal Province. Primary data utilized in this study were obtained from 200 participants that were selected through random sampling. The descriptive results indicated that the majority of the farmers experienced climate variability and employed carbon and water-smart agricultural practices. The study employed the Multivariate Probit Model and Count Data Model/GLM Correlation Test to analyze the adaptation strategies and the level of their implementation by the selected vegetable farmers. The first hurdle of the probit model results showed that education level and land size positively and significantly influence smallholder farmers' adaptation strategies, while marital status, household size, income source, soil type, membership of the association, and supply chain involvement had a significant and negative effect on adoption of adaptation strategies. The



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results from the second hurdle showed that household size, the total size of land used for vegetable production, sandy, silt, and loam soil had a significant and negative effect on the level of adaptation strategy used, whilst the total size of land owned had a positive and significant impact on the level of adaptation strategy used

by the smallholder vegetable farmers. The study concludes that education level and total land size are associated with improved farmers' climate variability adaptative capacity. The vegetable farmers' ability to adapt to climate variability challenges was negatively influenced by factors like marital status, household size, and soil type negatively impacted these strategies. The study recommends that the government considerably supports the Climate Smart Agriculture initiatives, such as alternatives like hot houses, training, credit access, and sustainable practices to enhance farmers' resilience and national food security. These may include but are not limited to alternatives like hot houses, as well as addressing barriers through training, credit access, and sustainable practices to enhance farmers' resilience and national food security.

Keywords: adaptation strategies; smallholder vegetable farmers; KwaZulu Natal; level of adaptation; climate variability

1. Introduction

Agriculture is a crucial sector that contributes to economic development, social well-being, and environmental sustainability [1,2]. It is a source of food, supports growth, and enhances productivity through cultivation expansion. Productivity and market efficiency of smallholder farmers are improved through modernization [3]. It significantly improves livelihoods and reduces food insecurity among rural households [4]. Agriculture contributes to 19.26% of employment in South Africa, with KwaZulu Natal (KZN) being the second largest contributor [5]. In South Africa, especially KZN agriculture, is a key sector, particularly for smallholder vegetable farmers. Smallholder vegetable farmers refer to those farmers who produce various vegetables (potatoes, cabbages, beetroot, spinach, tomatoes, etc.) mainly for family consumption and sell the surplus. These farmers produce vegetables that are mostly organic and contribute to food and nutrition security. Moreover, smallholder vegetable farmers play a huge role in ensuring local food access and contribute to the local community economy and poverty reduction in KZN. Despite the potential of smallholder farming, they are characterized by limited land access, poor storage facilities, poor infrastructure, and market orientation. Additionally, smallholder vegetable farmers are more susceptible to climate variability as they have poor managerial production skills and limited access to quality irrigation systems. This emphasizes the need for effective adaptation strategies to aid smallholder farmers in KZN [6].

Climate variability poses significant challenges to smallholder farmers in KZN, impacting their livelihoods and agricultural productivity. The vegetables that are grown by smallholder farmers have a low shelf life and are easily perishable; therefore, an increase in temperatures and erratic rainfall patterns result in a negative impact on the production, yield, and storage of the vegetables. However, smallholder vegetable farmers use adaptation strategies that enhance their resilience to climate variability, optimize their use of resources, and incorporate sustainable practices which boost their profits and yields [7]. These adaptation strategies include growing drought-resistant crops, crop diversification, adjusting planting dates, soil and water conservation practices, reducing livestock holdings, planting trees, extension services, remittances, family labor, and small-scale irrigation, mitigating climate variability effects [8–11]. Smallholder farmers benefit from using these adaptation strategies as they are cost-effective, do not require in-depth knowledge, and are easy to implement, though various adaptation strategies exist and are used, most farmers do not utilize them effectively [12]. Also, these adaptation strategies are environmentally friendly, easily accessible, and sustainable.

To strengthen the theoretical grounding of this chapter, the analysis is situated within broader conceptual and policy frameworks that guide climate adaptation globally and nationally. The Intergovernmental Panel on Climate Change (IPCC) typologies of adaptation, namely anticipatory, reactive, autonomous, and planned adaptation, offer a useful lens for interpreting the diversity of responses observed among smallholder farmers in KwaZulu-Natal. These typologies help differentiate adaptation strategies based on their timing and the extent of institutional involvement. In addition, the chapter aligns with South Africa's National Climate Change Adaptation Strategy (NCCAS), which outlines priority areas for building resilience in climate-sensitive sectors such as agriculture. Referencing these frameworks not only contextualizes the findings within established adaptation discourse but also underscores their policy relevance beyond the immediate study area.

Smallholder farmers' adaptation strategies to climate variability are influenced by awareness, resource access, household perception of climate change, awareness of climate-related risks, and perceived impact of climatic events socio-demographic characteristics, and the role of farmer groups and agricultural extension services [13–15]. Other factors include farming practices, information distribution, resource management, and community support. Enhancing the adaptive capacity of smallholder farmers through education, targeted interventions, and policy support is essential for building resilience and sustainable agricultural practices [16,17]. It is therefore important to understand these determining factors for enhancing farmers' resilience to climate variability and ensuring sustainable agricultural practices [18].

Previous studies by Hirpha et al. [19], Addis and Abirdew [20], and Ikua [21] have examined the factors influencing smallholder farmers' adaptation strategies in general; yet, none have specifically focused on smallholder vegetable farmers. Yet, the government of South Africa and other non-governmental organizations are strongly advocating for the consumption of vegetables to improve the food and nutrition security profile of the province and the country in general, creating a need to focus on these farmers. In regions

such as East Africa, studies like those by Mutekwa et al. [22] in Zimbabwe have explored how vegetable farmers adapt to climate change; yet, there remains a gap in research that investigates the specific adaptation strategies of vegetable farmers in South Africa. In Kenya, the work of Mwangi et al. [23] highlighted how vegetable farmers face unique challenges, including high susceptibility to extreme weather conditions and market volatility, but have not entirely studied the broader socio-economic factors that affect strategy selection.

While previous studies have explored the challenges farmers face in adopting effective adaptation strategies, such as limited knowledge and financial constraints, they have often overlooked the exclusive difficulties faced by smallholder vegetable farmers. These studies highlight external barriers like restricted access to inputs, inadequate infrastructure, and high transaction costs, which prevent farmers from accessing high-value markets. However, there is a notable gap in the literature regarding the specific factors influencing the choice of adaptation strategies and the extent to which these strategies are implemented, particularly for vegetable farmers. The focus on smallholder vegetable farmers is especially significant as vegetables, unlike staple crops, are more vulnerable to climate extremes and require specific adaptation strategies to address both environmental and market-related challenges. This study aims to address this gap by investigating the factors that influence the selection and implementation of adaptation strategies among smallholder vegetable farmers in KwaZulu Natal Province, offering valuable insights into a sector that has received limited attention in existing research.

2. Materials and Methods

2.1. Description of Study Area

This study was conducted in KwaZulu Natal (KZN), a province in South Africa. The province has a diverse topography and experiences high rainfall in January and dry conditions during June [24]. The annual maximum temperature experienced in the province is 24.77 °C and the minimum temperature of 19.7 °C. There is an average of 106.56 mm of precipitation every year. One of the main industries in the province's rural areas for employment is agriculture. The province has a diverse economy, with industry, tourism, and agriculture being its three main economic areas. The study focused on the entire province and covered all eleven districts as seen in Figure 1 below. The study area was chosen due to the current climatic variability, such as the flash floods and extreme heat, that has altered the agricultural production of smallholder farmers in the region. The effects of the COVID-19 pandemic and the looting have added pressure on the farmers and the quality and quantity of produce [25,26]. The KwaZulu Natal (KZN) province was selected as the study area due to its significant agricultural output, encompassing major crops such as sugarcane, maize, and subtropical fruits, coupled with its documented vulnerability to extreme weather events. To minimize selection bias, the research encompassed smallholder farmers across the entire provincial region.

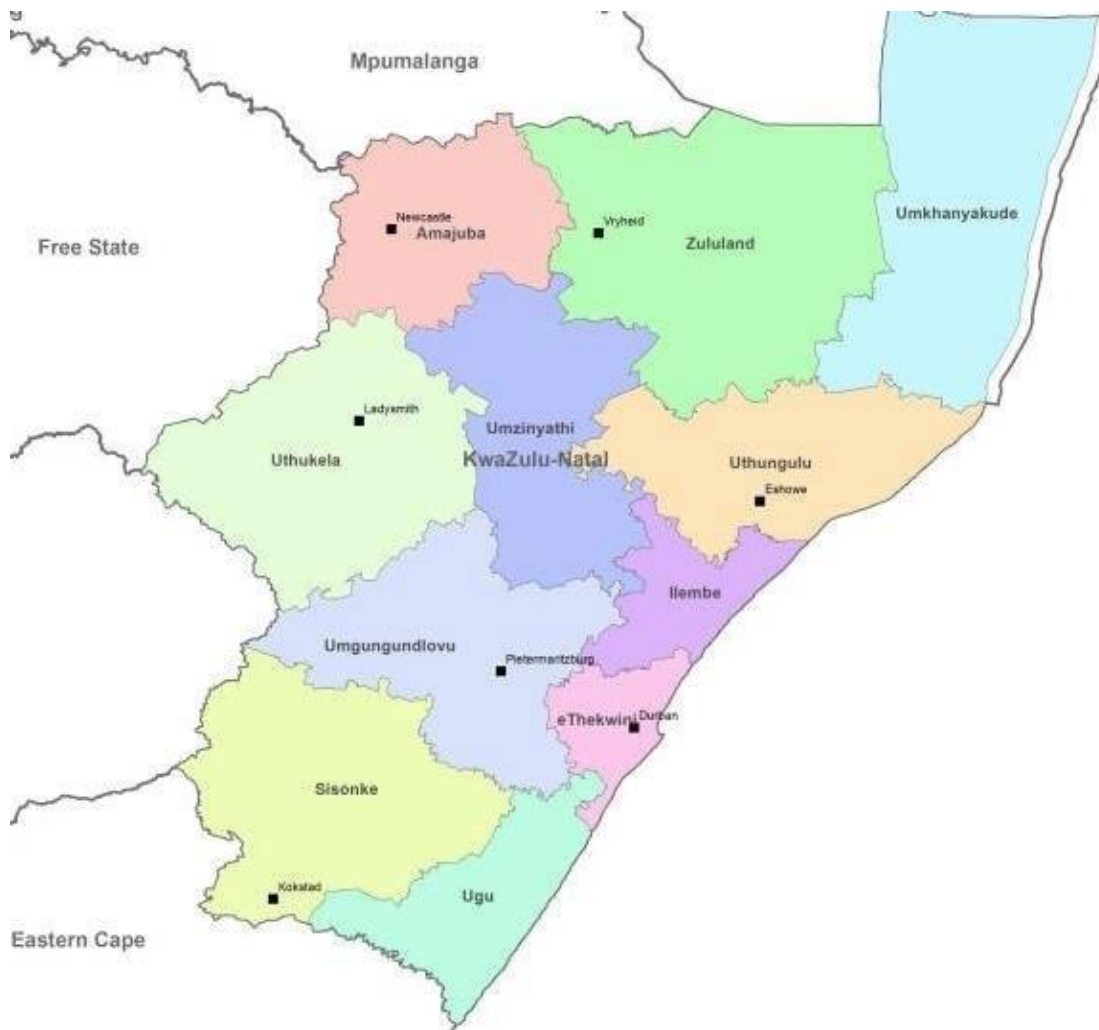


Figure 1. Map of the study area—KwaZulu Natal Province, South Africa (accessed from DAFF: https://www.researchgate.net/publication/346937802/figure/fig1/AS:972334794018817@1608834088348/Map-of-KwaZulu-Natal-district-municipalities-DAFF-nd_Q320.jpg, accessed on 8 July 2024).

2.2. Data Collection Method

This study applied a quantitative method approach. This approach is particularly useful for hypothesis testing, as it enables researchers to utilize statistical techniques to analyze data and draw evidence-based conclusions [27]. Data collection took place between December 2023 and March 2024. Ethical clearance was obtained from the Human and Social Science Research Ethics Committee (HSSREC)—HSSREC/00005925/2023. The data collected included quantitative methodologies to achieve an understanding of the factors that influence the choice and level of adaptation strategies among smallholder vegetable farmers in KwaZulu Natal Province. These included demographics, socio-economic characteristics, adaptation methods, levels of adaptation methods, and Climate Smart Agricultural practices. The data were not limited to the above-mentioned data. The adaptation strategies were formulated using data previously reported by smallholder farmers regarding their responses to climate-related challenges. This data formed the basis of how the adaptation strategies were defined and categorized.

The questionnaire administered to farmers included both closed and open-ended questions. These were enumerated by the researcher; however, if there were language barriers between the respondent and researcher, Zulu-speaking enumerators administered the questionnaires and focused group discussions. The questionnaires were audio-recorded with the participants' permission. This practice enhances transparency in research and

allows for the replication of studies, contributing to the overall reliability and validity of the research findings [28]. Simple random sampling was employed to ensure a diverse representation of smallholder vegetable farmers across different rural regions of KwaZulu Natal. A 95% confidence interval was employed with a 5% margin for error. This sampling technique is characterized by its simplicity and fairness, as it provides an unbiased way to select participants from a larger population [29]. This method is particularly useful when researchers aim to draw conclusions that apply to the entire population under study [30]. The sample size consisted of 200 smallholder vegetable farmers for the questionnaires, randomly selected from a sampling frame of 2530 farmers. These farmers were chosen because they were registered with local agricultural organizations or market operators in the province. While selecting farmers registered with local agricultural organizations may have excluded the unregistered farmers, these farmers share similar characteristics [31]. This ensured that there was a comprehensive representation of the smallholder farmers in the province.

2.3. Data Analysis

Once the fieldwork was completed, the questionnaires were checked for accuracy and completeness. Quantitative models and descriptive statistics were calculated using IBM SPSS (Statistical Package for Social Sciences), version 28; Excel was also used to analyze the quantitative data.

Various statistical and data science techniques were employed in this study. The integration of statistical tools and qualitative modeling techniques has been utilized to effectively manage large amounts of agricultural data, providing insights into complex agricultural processes [32].

The study employed a Multivariate Probit Model to analyze the factors influencing farmers' choices of multiple adaptation strategies, examining the probability of adopting several strategies simultaneously and considering the interdependence between them. The key variables considered in the ordered probit regression model were gender, age, education level, marital status, household size, number of years farming vegetables, whether farming was the participant's main source of income, total size of land owned (hectare), total size of land used for farming, type of soil – sand, type of soil – silt, type of soil – clay, type of soil – loam, whether the participant was a member of a farmers' association/co-operation and involved in any formal or informal food supply chain networks or associations. The application of the multivariate probit model in agricultural research facilitates the identification of factors that influence farmers' decisions to adopt specific agricultural technologies or practices. These models offer a robust framework for analyzing the complexities of adoption behavior, allowing researchers to uncover the underlying drivers of technology uptake and the interactions between different variables [33,34]. The Multivariate Probit Model was used to model outcomes of multiple binary dependent variables simultaneously, where these outcomes might be correlated. It extends the probit model to multiple equations [33]. The multivariate probit model allows researchers to examine multiple adaptation strategies simultaneously while accounting for the possibility that these choices are related. Unlike binary logistic or OLS models, it captures the interdependence between decisions, offering a more realistic analysis of complex farmer behavior. Additionally, a Count Data Model/GLM Correlation Test was used to analyze count data, such as the number of adaptation strategies implemented by each farmer. The data followed a normal distribution before the correlation analysis was conducted. Count data models are particularly useful when dealing with discrete variables that represent counts, such as the number of pests in a field or the frequency of a specific event. These models are valuable for analyzing agricultural data that involve non-negative integers and are commonly used in various agricultural studies [35]. Correlation tests were conducted to identify relationships between demographic factors, livelihood variables, and the number of adaptation strategies adopted. Statistical analyses were conducted using software such as Stata, version 18.

Equi dispersion, or the equality of variance and mean, is an assumption made by the Poisson distribution. When the variance is less than the mean, it is called under-dispersion, and when it is greater than the mean, it is called over-dispersion [36]. Using the method used by Abate and Addis [37], let y_i denote the number of occurrences at a specific time or exposure period, with a rate given by μ_i . The following equations outline the specifications for the Poisson regression model:

$$P(Y_i = y_i | \mu) = \frac{e^{-\mu_i} \mu_i^{y_i}}{y_i!}, \mu_i > 0, i = 1, 2, \dots, n, \text{ and } y_i = 0, 1, 2, 3, \dots \quad (1)$$

The equation can be represented further by

$$\mu = \exp(\beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \dots + \beta_k x_{ki}) \quad (2)$$

In this study, y_i represents the value of an event count outcome variable with a mean parameter of μ_i that occurs during a specific time or exposure period [37]. Assumed to be a non-linear function of the independent variables, μ_i represents the mean and variance of the Poisson distribution. β_0 is the intercept of the model, where the coefficients of independent variables are denoted as $\beta_1, \beta_2, \dots, \beta_k$ and the number of explanatory variables [38]. Table 1 indicates the expected outcomes of the variables.

Table 1. Description of variables (own source).

Variable	Description of Variable	Expected Outcome
Gender	Dummy (1 = Male, 2 = Female)	–
Age	Measured in numbers	–
Education level	Continuous (1 = No formal schooling, 2 = Primary, 3 = Secondary, 4 = Tertiary and above)	+
Marital status	Continuous (1 = Single, 2 = Married, 3 = Divorced, 4 = Widowed)	+
Household size	Measured in numbers	+
Number of years farming – vegetables	Measured in numbers	+
Is farming your main source of income?	Dummy (1 = Yes, 2 = No)	+
Total size of land owned (hectare)	Measured in numbers	+
Total size of land used for Farming.	Measured in numbers	+
Type of soil – Sand	Dummy (1 = Yes, 2 = No)	–
Type of soil – Silt	Dummy (1 = Yes, 2 = No)	+
Type of soil – Clay	Dummy (1 = Yes, 2 = No)	–
Type of soil – Loam	Dummy (1 = Yes, 2 = No)	+
Are you a member of a farmers' association/co-operation?	Dummy (1 = Yes, 2 = No)	+
Involved in any formal or informal food supply chain networks or associations	Dummy (1 = Yes, 2 = No)	+

Source: Survey data.

3. Results

3.1. Descriptive Results

3.1.1. Demographic Characteristics of Smallholder Farmers in KwaZulu Natal

The sociodemographic characteristics of surveyed smallholder farmers are summarized in Table 2 using descriptive statistics. The data show that 85% of the surveyed population relies primarily on farming for their income, while 15% do not. Table 2 illustrates that most participants were male (65%), and the average age group was between 40 and 53 years (30%). Additionally, 50.5% of smallholder farmers had completed secondary education. Age and education levels significantly influence the adaptation strategies of smallholder farmers. Less educated and older farmers are more inclined to use traditional

practices and are generally more hesitant to adopt modern strategies to combat climate variability [39].

Table 2. Demographics of the surveyed population.

Variable		Frequency (n = 200)	Percentage (%)
Gender	Male	130	65
	Female	70	35
Education level of respondents	No Formal Education	12	6
	Primary	50	25
	Secondary	101	50.5
	Tertiary and above	37	18.5
Household Size	1–2	53	26.5
	3–4	75	37.5
	5–6	37	18.5
	7–8	14	7
	9–10	11	5.5
	11–12	8	4
	13–14	2	1
Age	26–39	45	22.5
	40–53	60	30
	54–67	56	28
	68–81	34	17
	82–88	5	2.5
Is farming the main source of income	Yes	170	85
	No	30	15
Part of a:	Farmers association	66	33
	Cooperation	53	26.5
	Not applicable	81	40.5
Did the respondent experience climate variability	Yes	172	86
	No	16	8
	I do not Know	12	6

The most common household size among the respondents was 3–4 people (37.5%), while the least common was 11–12 members (4%). Most of the sample population were household heads (66.5%). According to Table 2, 40.5% of the respondents did not belong to any farmers' groups, 33% were part of farmers' associations, and 26.5% were involved in cooperatives. Membership in these groups often exposes farmers to valuable information and increases their likelihood of adopting modern adaptation strategies [40]. Smallholder farmers are crucial to South Africa's agricultural sector, and Table 2 shows that 86% of the sample experienced climate variability, 8% did not, and 6% were unsure of what climate variability entails. This means that a lot of vegetable farmers are affected by climate variability, thus prompting the farmers to adopt certain strategies to mitigate the situation.

3.1.2. Smart Agricultural Practices Used by the Smallholder Farmers in KwaZulu Natal

Climate-smart agricultural practices are designed to enhance the performance and resilience of smallholder farmers [41]. A significant number of farmers are engaged in seed banking (93.5%) and actively share information with colleagues (87%), reflecting their knowledge of these practices. As shown in Figure 2, many surveyed farmers utilize carbon-smart agricultural techniques such as minimum tillage, organic manure, and crop rotation. These practices aim to improve sustainability and highlight the importance of understanding climate-smart agriculture for successful adoption [42].

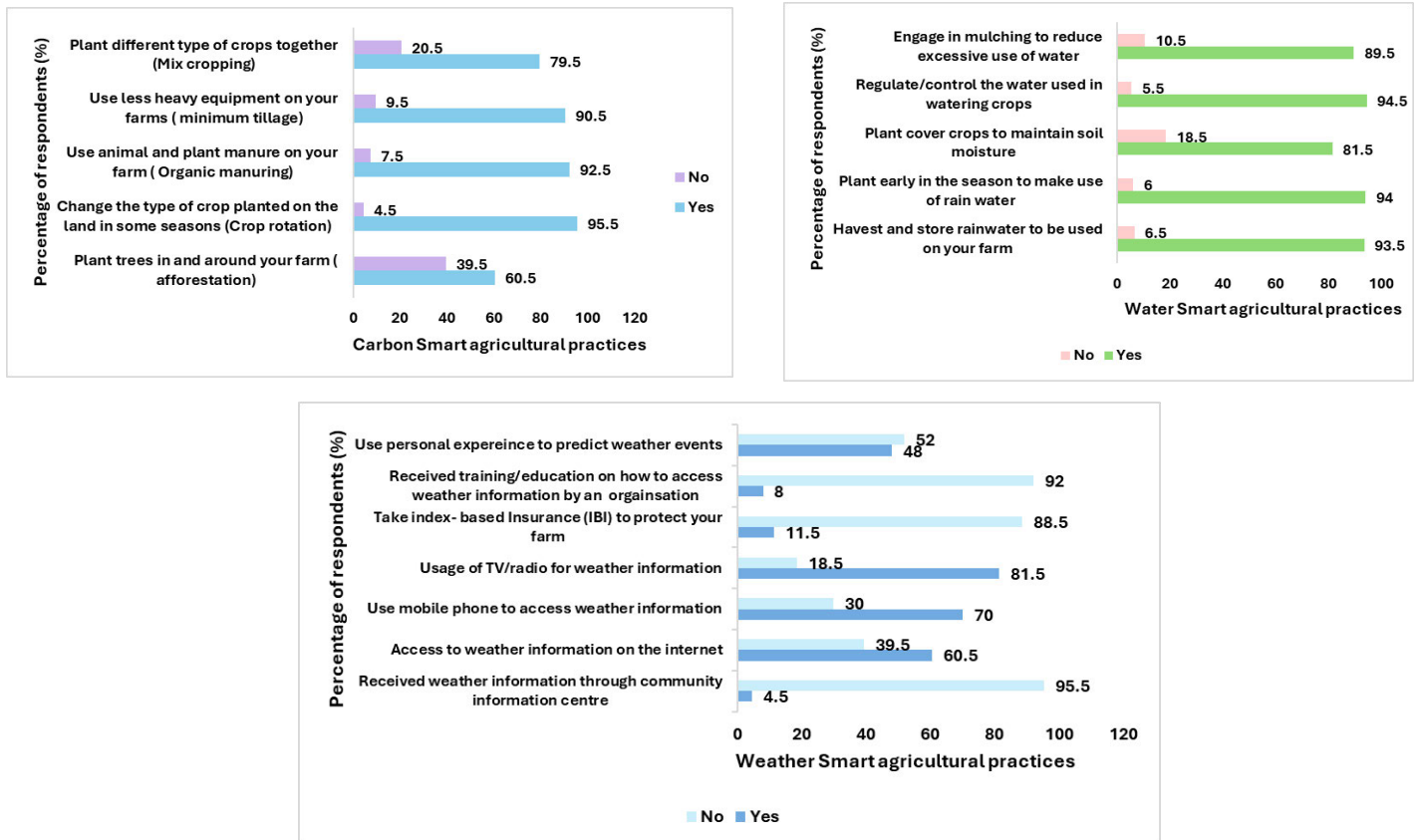


Figure 2. Smart agriculture practices used by smallholder farmers.

Figure 2 illustrates that water-smart practices are prevalent among farmers, with 94.5% controlling water use, 94% planting early to utilize rainwater, and 93.5% harvesting and storing rainwater. Employing both water- and nitrogen-smart methods is crucial for sustainable food production, mitigating the adverse effects of climate variability, and enhancing climate resilience. Integrating these practices can lead to increased crop yields, optimized resource use, and long-term agricultural sustainability [43].

Energy-smart practices are also common among smallholder farmers, with 56% composting crop residues, 32.5% using solar equipment, and 38% opting for fuel-efficient vehicles. Figure 2 shows that weather-smart practices include using TV/radio for weather updates (81.5%) and mobile phones for weather information (70%). Combining weather and energy-smart practices can enhance sustainability and productivity, helping farmers build resilience against climate variability [44].

3.1.3. Reasons Why Smallholder Farmers Did Not Use Certain Adaptation Strategies in KwaZulu Natal

The findings of this study showed a widespread adoption of diverse adaptation strategies among the sampled smallholder farmers. Specifically, the data indicated high implementation rates across multiple practices: crop diversification (95%), annual crop rotation (95.5%), minimum tillage (90.5%), rainwater harvesting for irrigation (93.5%), and organic manure application (92.5%). However, the adoption of these agricultural practices was constrained by several significant barriers, including financial limitations, motivational deficits, labor constraints, methodological inefficiencies, and insufficient awareness of available strategies. Addressing these challenges necessitates a comprehensive intervention framework encompassing policy reforms, financial mechanisms, and educational initiatives [7,9]. Demographic analysis showed notable correlations between adoption

rates and farmer characteristics. Age emerged as a significant determinant, with younger agricultural practitioners demonstrating a greater propensity to implement climate-smart practices compared to their older counterparts. Furthermore, educational attainment exhibited a positive association with adoption rates, as farmers with secondary and tertiary qualifications showed an increased inclination toward implementing climate-smart agricultural methodologies. Figure 3 shows that the most common reasons for not using certain adaptation strategies were lack of motivation, ineffective methods, and financial constraints. As depicted in Figure 3 below, 15.5% of the surveyed population did not plant trees alongside their crops due to lack of money. “Lack of money” emerges as the most cited reason for not adopting strategies such as crop diversification, intercropping, cover cropping, and minimum tillage. This aligns with the established literature, suggesting that financial barriers are a critical constraint for smallholder farmers, as many strategies require upfront investment in seeds, inputs, or equipment [45]. A larger percentage (66%) of the respondents felt that leasing their land was a bad method; this is because they were scared to lose their land. Leasing property for smallholder farmers can be very detrimental because of financial stresses, power imbalances, and social ramifications [45,46]. The prevalence of financial constraints suggests that resource-limited farmers are unable to shift to more resilient practices, despite their potential to mitigate climate risks. Also, a high percentage of respondents indicated “I don’t know” as a reason for not adopting certain strategies, particularly for “Buy insurance”. This implies significant knowledge gaps regarding the existence, functioning, or benefits of agricultural insurance as a risk management tool. This finding highlights the need for targeted extension services or education campaigns to raise awareness of underutilized adaptation strategies [46,47]. It frequently results in community unrest, displacement, and decreased agricultural productivity in addition to worsening financial instability.

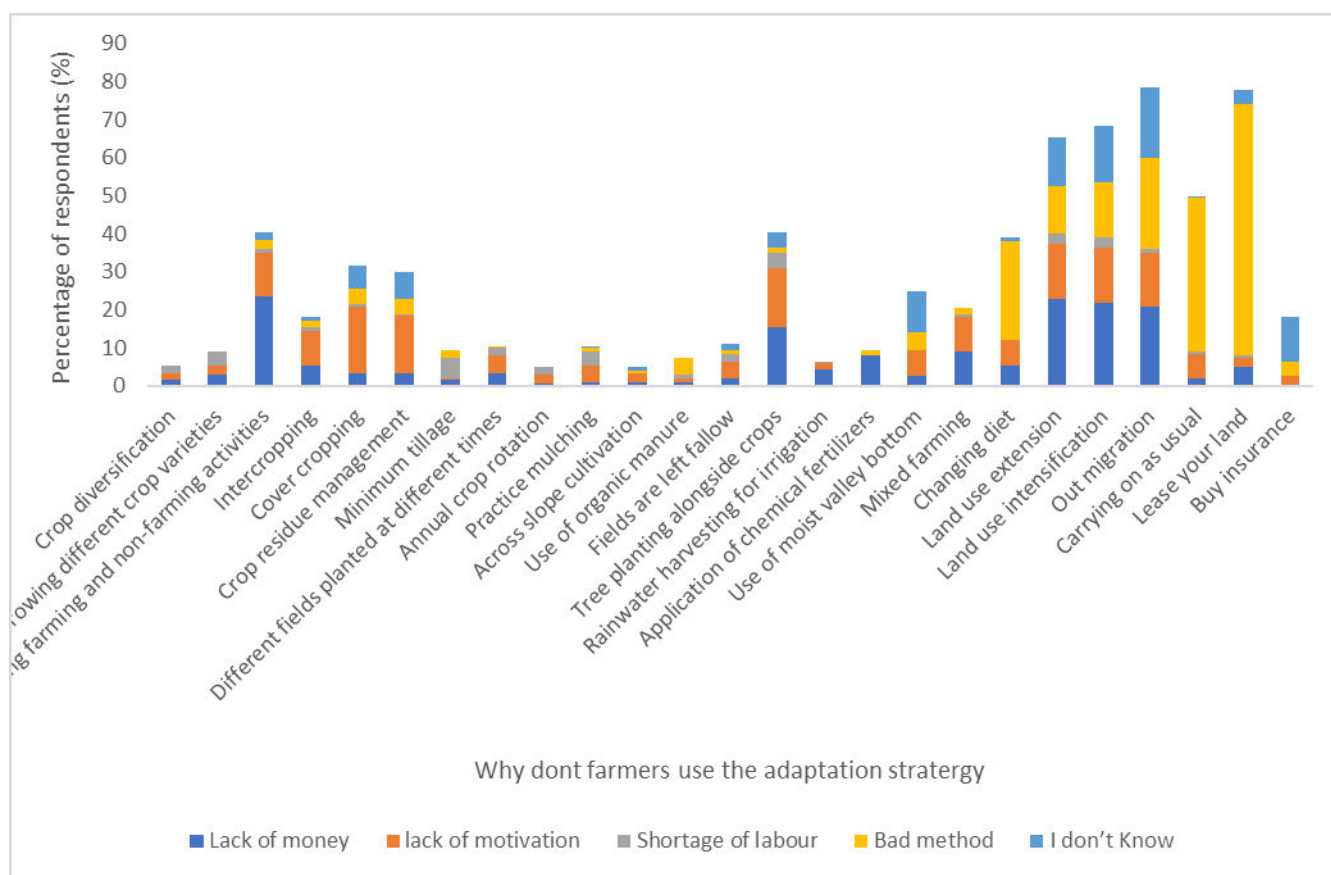


Figure 3. Reasons why the sampled population did not use certain adaptation strategies.

For strategies like “Carrying on as usual”, “Lack of motivation” is a notable barrier. This reflects a tendency among some farmers to resist change or remain reliant on traditional practices, even when they are vulnerable to climate risks. Lack of motivation often leads to reluctance to change, resulting in the use of inappropriate methods due to limited knowledge [47]. Insufficient funds restrict farmers’ ability to purchase inputs and equipment and hinder their access to credit for essential investments in adaptation measures, further exacerbating their vulnerability to climate variability [48]. These combined factors can create a cycle of challenges for smallholder farmers.

3.2. Empirical Results

3.2.1. Determinants of Adaptation Strategies Using Extended Ordered Probit Regression

Table 3 shows the factors that influence the adaptation strategies used by the sampled smallholder farmers of KwaZulu Natal. The study focused on five adaptation strategies that were selected as they had a significant impact on the variables. These adaptation strategies were as follows: carrying on as usual, changing diet, tree planting alongside crops, diversifying farming to non-farming activities, and land use intensification. To estimate the severity of these factors on the adaptation strategies, the ordered probit regression model was used. Table 3 provides insight into the estimated results of the ordered probit regression model.

The results showed that the education level had a positive and significant influence on the “tree planting alongside crops” and “land use intensification” adaptation strategies. This implies that the higher the education level of the farmer, the more likely they were to use the adaptation strategy. The results agreed with Zamasiya et al. [49], who stated that without adequate education, smallholder farmers have lower agricultural productivity and increased susceptibility to climate hazards. This also means that if farmers have a higher education level, they are more likely to implement adaptation strategies to combat the effects of climate variability [50,51]. The findings suggest that education has varying effects on the adoption of different adaptation strategies. While it may enhance the uptake of certain practices, it appears to discourage others, possibly due to differences in perceived cost, effort, or the nature of available information.

Education is positively associated with adopting sustainable strategies. A unit increase in education level significantly increases the likelihood of planting trees, alongside crops and moderately promotes land use intensification. Education improves farmers’ ability to understand and implement advanced techniques, including agroforestry and intensive land management practices. These findings align with Hlatshwayo et al.’s [39] existing evidence, suggesting that education enhances the adoption of climate-resilient strategies. Marital status had a negative influence on land use intensification, with significance.

This means that married farmers were less likely to intensify land use due to household responsibilities and risk management priorities, making them more cautious and less inclined to adopt advanced techniques or increase inputs. This finding contrasts with the study conducted by Airflo [52], which found that land use intensity increased with marital status. However, these findings align with the study conducted by Okon et al. [53], who stated that due to household duties and risk management concerns, married farmers are less likely to intensify land usage, which makes them more conservative and less likely to embrace adaptation strategies. This relationship emphasizes the need for initiatives that address social dynamics and environmental sustainability and is influenced by household size and socioeconomic characteristics.

Table 3. Determinants of adaptation strategies using extended ordered probit regression.

Variable	Carrying on as Usual			Changing Diet			Tree Planting Alongside Crops			Diversifying Farming to Non-Farming Activities			Land Use Intensification		
	Coefficient	St. Errs.	<i>p</i> - Value	Coefficient	St. Errs.	<i>p</i> - Value	Coefficient	St. Errs.	<i>p</i> - Value	Coefficient	St. Errs.	<i>p</i> - Value	Coefficient	St. Errs.	<i>p</i> - Value
Gender	−0.208	0.239	0.385	0.120	0.228	0.600	0.146	0.217	0.502	−0.081	0.209	0.698	0.137	0.228	0.549
Age	−0.010	0.012	0.405	−0.003	0.012	0.813	0.011	0.011	0.350	−0.010	0.011	0.377	0.019	0.012	0.108
Education Level	0.191	0.165	0.246	−0.263	0.160	0.100	0.302	0.149	0.042 **	0.168	0.150	0.261	0.286	0.162	0.077 *
Marital status	−0.103	0.148	0.485	−0.026	0.145	0.860	0.059	0.135	0.665	0.015	0.130	0.910	−0.333	0.154	0.031 **
Household size	0.034	0.043	0.426	−0.083	0.042	0.050 **	−0.070	0.040	0.081 *	−0.091	0.040	0.025 **	−0.040	0.045	0.383
Number of years farming—vegetables	0.019	0.013	0.127	−0.012	0.012	0.345	−0.008	0.012	0.514	0.007	0.011	0.530	−0.009	0.012	0.450
Is farming your main source of income?	0.368	0.330	0.264	−0.909	0.313	0.004 ***	−0.317	0.280	0.258	−0.091	0.285	0.748	−0.599	0.321	0.062 *
Total size of land owned (hectare)	0.038	0.012	0.001 ***	0.018	0.011	0.098 *	0.019	0.010	0.064 *	0.007	0.010	0.471	0.015	0.010	0.126
Total size of land used for Farming.	−0.173	0.041	0.000 ***	−0.183	0.035	0.000 ***	−0.031	0.023	0.165	0.003	0.023	0.901	0.025	0.023	0.276
Type of soil—Sand	−1.131	0.272	0.000 ***	−0.848	0.282	0.003 ***	0.147	0.242	0.544	−0.279	0.238	0.241	−0.074	0.246	0.765
Type of soil—Silt	−0.841	0.286	0.003 ***	−0.992	0.292	0.001 ***	0.173	0.261	0.507	−0.333	0.260	0.200	−0.632	0.279	0.023 **

Type of soil—Clay	-0.576	0.293	0.049 **	-0.384	0.292	0.189	-0.217	0.263	0.410	0.269	0.254	0.289	-0.456	0.259	0.078 *
Type of soil—Loam	-0.576	0.267	0.031 **	-0.883	0.283	0.002 ***	-0.050	0.255	0.845	0.078	0.251	0.755	-0.487	0.265	0.066 *
Are you a member of a farmers' association/co-operation?	-0.151	0.087	0.082 *	0.271	0.086	0.002 ***	0.112	0.075	0.138	0.190	0.076	0.012 **	0.148	0.079	0.060 *
Involved in any formal or informal food supply chain networks or associations	0.200	0.251	0.426	-0.586	0.252	0.020 ***	0.158	0.216	0.466	-0.555	0.229	0.015 **	-0.426	0.234	0.069 *
Cons	4.883	1.795	0.007 ***	9.257	2.030	0.000 ***	-1.548	1.617	0.338	1.386	1.629	0.395	2.033	1.704	0.233

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Household size showed a negative and significant influence on changing diet, diversifying farming to non-farming activities, and planting trees alongside crops. This implies that smallholder farmers with large household sizes limited their use of the above-mentioned adaptation strategies. This could be because when a household has more members, its resources are more depleted and thus reduce its adaptive capacity. This contradicts research by Gebre et al. [54], which states that larger household sizes increase the resilience and sustainability of the farm against climate variability. This is because larger household sizes have an increase in the labor force and, therefore, make it easier for the household to implement adaptation strategies.

The results of this study also exhibited that income had a negative and significant association with changes in diet and intensification of land use. Farming households are significantly less likely to adapt to changing diets. This finding reflects reliance on farm produce for household consumption, limiting the ability to shift dietary practices. This is a key consideration for food security policies targeting farming households. Therefore, this suggests that as smallholder farmers' income increases, they are less likely to utilize these adaptation strategies. The findings align with Bousmaha and M'Zali [55], who observed that higher income among smallholder farmers is associated with a decreased likelihood of employing certain adaptation strategies. Generally, higher income is linked to increased resources and potentially better adoption of advanced agricultural practices. This is also contrary to Workalemahu and Dawid [9], who stated that increased income levels give smallholder farmers the means to acquire inputs, technology, and knowledge that can improve their ability to withstand the effects of climate variability.

The total size of land owned by the farmers positively and significantly affected the following adaptation strategies. Carrying on as usual: the positive and highly significant relationship suggests that farmers with larger landholdings are more likely to continue their current practices without major changes. Farmers with substantial landholdings may experience less pressure to adopt drastic adaptation strategies, as they can afford to rely on their existing practices to sustain productivity. Larger plots of land may provide a safety net by enabling diversification within the farm, thus reducing the need for visible external adaptations [56,57]. Changing diet: There is a weak significant negative relationship between landholding size and the likelihood of changing diets. Farmers with smaller landholdings are more likely to change their diets as a coping mechanism. This is likely because they rely more heavily on subsistence farming and are more exposed to food insecurity when yields drop due to climate change. Conversely, farmers with larger plots are better able to produce sufficient quantities of diverse crops for household consumption, reducing the need to adapt by changing dietary patterns. Changing diets is often a last-resort adaptation strategy, typically employed when other measures fail [56]. Smaller landholders may lack the resources to pursue other strategies, making dietary changes an unavoidable response to resource scarcity and tree planting alongside crops.

This infers that the larger the size of land owned, the farmer is more likely to employ the mentioned adaptation strategies. Studies by Kumwenda and Chirwa [56]; and Hellin et al. [57] are in line with the findings and suggest that the larger the size of land owned by farmers, the more likely and willing they are to explore different adaptation strategies to improve their crop productivity as well as overall health and increase their resistance to climate variability. The total size of land used had a negative and significant effect on the following adaptation strategies: carrying on as usual and changing diet. This proposes that the larger the land used for vegetable farming, the smaller the chance that the farmer will change their diets or carry on as usual. These findings are in line with findings from Maitra et al. [58]; and Yang et al. [59], who found a negative correlation between carrying on as usual and the size of land used for farming. These studies suggested that farmers try and

reduce their risk of crop failure by using intercropping; hence, the larger the size of land that they use for crop production, the less likely the farmer is to carry on as usual.

Soil types were found to significantly and negatively influence the adaptation strategy of “carrying on as usual”. This indicates that vegetable smallholder farmers with these soil types were less likely to continue with the “carrying on as usual” approach. The findings are in agreement with Naazie et al. [11]; and Phromthep [60], who found that smallholder farmers with poor soil conditions are less inclined to adopt new adaptation strategies and tend to stick with traditional practices. This tendency arises from declining productivity, economic pressures, and limited resources, which drive farmers to rely on existing methods despite their potential unsustainability, due to the challenges related to soil fertility and the lack of viable alternatives. Farmers who had sand, silt, and loam soil had a negative and significant effect on the adaptation strategy “changing diet”. This indicates that farmers with those types of soils were reluctant to consider adopting a change in diet strategy. This means that farmers with these types of soils tend to resist changing their dietary practices, likely due to stable crop yields, economic stability, and strong cultural traditions. These findings align with studies conducted by Weil and Brady [61]; and Elias [62], who found that these factors (stable crop yields, economic stability, and strong cultural traditions) lead smallholder farmers to prefer traditional diets and familiar agricultural practices, as these generally ensure sufficient food security.

The adaptation strategy of land use intensification was negatively impacted by silt, clay, and loam soil. This suggests that farmers with silt, clay, and loam soil did not intensify their land use. These findings are in line with Xie et al. [63]; and Akanmu [64], who found that the favorable fertility and productivity of silt, clay, and loam soils, along with economic and environmental factors, lead farmers to prefer stable land use techniques over increased ones. These farmers will probably put soil health and sustainability ahead of intensifying land usage, resulting in yields that are sufficient even in the absence of extra inputs.

The results indicate that membership in farmers’ associations or cooperatives by smallholder farmers had a positive influence on adaptation strategies, such as changes in diet, diversification of farming and non-farming activities, and land use intensification. This suggests that farmers in these groups are more likely to make significant changes in these areas. According to Karlan et al. [65], which aligns with the findings, the support and resources provided by these organizations often promote stability, which may lead members to adhere to traditional practices.

Conversely, being a member of a farmers’ association or cooperative negatively and significantly impacted the use of the adaptation strategy of carrying on as usual, by the smallholder farmers. This implies that the farmers who were members of farmer’s associations or cooperatives were less likely to carry on as usual. These findings agree with Alfirdaus et al. [66]; and Magakwe and Olorunfemi [67], who stated that farmers in associations or cooperatives are more likely to adapt and innovate their practices compared to those working independently, due to the enhanced resources, information, and collective bargaining power provided by these groups. Membership in cooperatives also improves access to formal markets, better prices, and sustainable practices, fostering a collaborative culture that supports resilience and adaptability in changing agricultural conditions.

The results showed that involvement in any formal or informal food supply chain network or association by smallholder farmers had a negative and significant impact on the smallholder farmers changing their diets and diversifying their farming and non-farming activities. This indicates that farmers who engaged in such networks were less likely to adopt these adaptation strategies. This finding aligns with Garcia and Smith [68]; and Schreiber et al. [69], who noted that formal or informal food supply systems provide stability, security, and social cohesiveness, thus, making smallholder farmers within these

networks less inclined to implement adaptation measures. The authors explained that this resistance to change stems from the farmers' focus on maintaining existing connections and practices rather than exploring new approaches. Involvement in supply chains may discourage smallholder farmers in KwaZulu Natal (KZN) from adopting new adaptation strategies, as they often prioritize maintaining stable, secure networks with known partners. This conservative approach to risk management can limit their willingness to experiment with new methods or innovations that could disrupt established relationships or practices [8,68]. To address these challenges, interventions could focus on the following:

- Demonstrating how adaptation strategies can enhance rather than threaten supply chain relationships;
- Working with supply chain partners to gradually incorporate climate-smart practices.

3.2.2. Factors Influencing the Level of Adaptation Strategies Among Smallholder Vegetable Farmers, KwaZulu Natal

The results of the level of implementation of the adaptation strategies and the factors that influence their usage by smallholder farmers are presented in Table 4. As shown in Table 4, the estimation of the Akaike information criterion (AIC) and Bayesian information criterion (BIC) are essential to indicate a better model in analyzing count data of the level of adoption of adaptation strategies. In this study, the Poisson regression model was used, the AIC value was 704.895, and the (BIC) value was 760.967. Household size, the total size of land owned, the total size of land used for vegetable farming, as well as sandy, silt, and loam soil were the main factors that significantly affected the level of adaptation strategy adopted by smallholder farmers in the study area. The results showed that the household size negatively and significantly influenced the adoption of the level of adaptation strategies by smallholder farmers. This indicates that smallholder farmers' adoption of the adaptation method declines as family size grows. As was previously said, when households grow larger, people become less willing to take risks and produce primarily for their own survival rather than for the sake of selling. As a result, they are less likely to take part in interventions. Investment in infrastructure is crucial for enhancing climate resilience, not only at the farm level but also across regions. Improved roads, irrigation systems, and storage facilities strengthen supply chains and enable broader adaptation to climate-related risks. The results were contrary to Adams and Mutunga [70], who stated that households with larger size of land are more likely to adapt as they can afford to make the necessary investments. According to these studies, farmers adopt more adaptation strategies to save labor and guarantee a higher crop yield as their household size increases.

The results showed that the total size of land owned by the smallholder farmers had a positive and significant influence on the level of adaptation strategy used. This indicates that the larger the size of land owned by the smallholder farmers, the higher their level of adaptation, suggesting that land size improves the household's adaptive capacity. These findings align with studies conducted by Irawan and Syakir [13]; and Gudina and Alemu [71], who found that larger land holdings enable smallholder farmers to adopt diverse and sustainable agricultural practices, such as crop rotation and improved seed usage, which are crucial for adapting to climate variability. A study conducted by Workalemahu and Dawid [9] also aligns with the study and states that the economic stability provided by larger farms supports investment in innovative technologies and better access to markets and resources, further enhancing farmers' ability to implement effective adaptation strategies.

Table 4. Factors influencing the level of adaptation strategies among smallholder vegetable farmers, KZN.

Variable	Poisson			Marginal Effect		
	Coef.	St. Err.	p-Value	dy/dx	Std.	p-Value
Gender of respondent	0.008	0.099	0.939	0.019	0.249	0.939
Age of respondent	-0.001	0.005	0.906	-0.002	0.013	0.906
Education level	0.083	0.071	0.247	0.208	0.179	0.246
Marital status	-0.014	0.061	0.822	-0.034	0.152	0.822
Household size	-0.038	0.020	0.056 *	-0.096	0.050	0.055 *
Number of years farming (vegetable)	0.000	0.005	0.978	-0.000	0.013	0.978
Is farming your main source of income	-0.125	0.130	0.336	-0.314	0.326	0.336
Total size of land owned (hectare)	0.009	0.004	0.030 **	0.022	0.010	0.029 **
Total size of land used for vegetable production	-0.029	0.012	0.015 **	-0.073	0.030	0.014 **
Type of soil—Sand	-0.260	0.113	0.021 **	-0.653	0.282	0.021 **
Type of soil—Silt	-0.251	0.117	0.032 **	-0.631	0.293	0.031 **
Type of soil—Clay	-0.132	0.116	0.256	-0.332	0.291	0.255
Type of soil—Loam	-0.227	0.112	0.042 **	-0.571	0.281	0.042 **
Are you a member of a farmers' association/co-operation	0.051	0.034	0.138	0.127	0.086	0.137
Involved in any formal or informal food supply chain networks or associations	-0.096	0.105	0.362	-0.241	0.265	0.362
Constant	2.540	0.739	0.001 ***			***
Mean dependent var	2.625					
Pseudo r-squared	0.064					
Chi-square	46.117					
Akaike crit. (AIC)	704.895					
Bayesian crit. (BIC)	760.967					
SD dependent var	1.433					
Number of obs	200.000					
Prob > chi2	0.000					

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The size of land used for vegetable production by smallholder farmers had a negative and significant influence on the level of adoption of adaptation strategies, which indicates that the larger the land used for vegetable production, the lower the level of adaptation strategies used by smallholder farmers. These findings contradict studies conducted by Asfaw et al. [72]; and Lengoiboni et al. [73], who found that fear of risks, financial restrictions, restricted access to resources and knowledge prevent smallholder farmers with small land sizes from using adaptation techniques. These limitations prevent the adoption of potentially helpful practices.

Lastly, sandy, silt, and loam soil showed a negative and significant influence on the level of adaptation strategy. This means that these soil types did not improve the adaptive capacity of the smallholder farmers. These results were confirmed by Verchot et al. [74]; and Keesstra et al. [75] who explained that loam, silt, and sandy soil types can have a detrimental effect on the usage of adaptation strategies by smallholder farmers. They mentioned that farmers may face unique difficulties when the proportion of these soil types rises, which makes it more difficult for them to put effective adaptation plans in place. This association emphasizes how crucial it is to take socioeconomic and soil features into account when creating policies and other measures meant to increase agricultural resilience.

4. Conclusions and Policy Recommendations

The implementation of adaptation techniques enhances smallholder farmers' resilience to the effects of climate variability while also helping them to raise agricultural productivity. This study assessed the factors that influence the choice and level of adaptation strategies

among smallholder vegetable farmers in KZN. The findings showed that education level and total size of land owned had a positive and significant influence on adaptation strategies used by the smallholder farmers. This suggests that access to information and training should be prioritised as foundational steps. These enable smallholder farmers to better understand and utilise subsequent support, such as credit facilities and input services. By first strengthening knowledge and adaptive capacity through training and extension services, farmers are more likely to effectively access and benefit from financial and infrastructural interventions. This staged approach could contribute to a more nuanced and impactful policy roadmap. In contrast, marital status, household size, farming as a main source of income, type of soil, sand, silt, clay, and loam, being a member of a farmers' association, and involvement in any formal or informal supply chain network had a negative and significant influence on the adaptation strategies. Household size, the total size of land used for vegetable production, sandy, silt, and loam soil had a significant and negative effect on the level of adaptation strategy used, whilst the total size of land owned had a positive and significant impact on the level of adaptation strategy used by the smallholder vegetable farmers.

It is concluded that socioeconomic characteristics had a considerable influence on the likelihood of employing the adaptation strategy and the level of the adaptation strategy used by the smallholder vegetable farmers in KwaZulu Natal. Education level and total land size are associated with improved farmers' climate variability adaptive capacity. Training smallholder farmers on climate variability and adaptation methods can greatly benefit them by highlighting the importance of these strategies given current climatic conditions.

The study recommends that the government considerably supports the Climate Smart Agriculture initiatives. These may include but are not limited to alternatives like hot houses and addressing barriers through training, credit access, and sustainable practices to enhance farmers' resilience and national food security. Additionally, overcoming barriers such as limited financial resources and motivation through targeted interventions, training, extension services, improved credit access, and sustainable practices is crucial for enhancing farmers' resilience and ability to adapt to climate variability.

5. Limitations of This Study

The study acknowledges potential biases inherent in self-reported data from questionnaires and FGDs. The sample size, though sufficient for preliminary insights, may not encompass the full diversity of experiences among smallholder farmers in KwaZulu Natal. Furthermore, the four-month data collection period may not adequately capture seasonal variations and longer-term trends in climate impacts. A limitation of the study is the absence of analysis on the role of collective or cooperative structures, such as farmer group membership, which may influence adaptation outcomes. Future research could explore this dimension to better understand social factors shaping adaptation.

By employing a rigorous approach and adhering to ethical standards, this study seeks to provide a comprehensive understanding of the factors influencing the selection of adaptation strategies among smallholder vegetable farmers in rural KwaZulu Natal. The findings will offer valuable insights into the development of adaptive strategies and policies to support sustainable agricultural practices in the region. This study's scope was limited to smallholder farmers registered with local agricultural organizations and market operators in KwaZulu Natal. While these registered farmers typically share common characteristics with the broader farming community, the findings may not fully represent unregistered smallholder farmers in the region. Future research should expand the sample to include unregistered smallholder farmers, which could provide more comprehensive insights into the entire smallholder farming sector in KwaZulu Natal. This broader inclusion would help validate the current findings and potentially identify unique challenges or needs specific to unregistered farmers.

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CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

8.1. Summary

The productivity and income of the smallholder farmers can increase if it is strengthened through interventions. The challenges faced by climate change caused a significant amount of stress to the smallholder farmers, thus negatively affecting their livelihoods.

The purpose of the study was to understand how climate change affects the food supply chain of smallholder farmers in KwaZulu Natal, South Africa. The specific objectives of the study aim to assess the impact of climate change on the food supply chain in Africa, with a focus on South Africa and KwaZulu Natal. It includes analysing the food supply chain in KwaZulu Natal through mapping techniques, evaluating how perceptions of climate change affect the income of smallholder vegetable farmers in the province, and examining their views on climate change's influence on food security. Additionally, the study seeks to identify the factors influencing the adoption and extent of adaptation strategies among smallholder vegetable farmers in KwaZulu Natal, in response to climate-related challenges. The study makes a significant contribution to the understanding of climate change adaptation within South Africa's food systems, particularly in the context of smallholder vegetable farming in rural KwaZulu Natal. While existing literature has extensively explored the impacts of climate change on staple crops like maize, this study addresses a critical knowledge gap by focusing on vegetable production an essential yet under-researched component of local nutrition, income generation, and rural food security.

Through a mixed-methods approach, the research provides a detailed assessment of how climate variability affects the livelihoods and food supply chains of smallholder vegetable farmers and identifies the socioeconomic and environmental determinants that influence the choice and intensity of adaptation strategies. Findings reveal that factors such as education level and land ownership significantly increase the likelihood of employing adaptation strategies, while variables like household size, soil type, and lack of market integration negatively affect adaptive Descriptive capacity.

Descriptive statistics, frequencies, Seemingly Unrelated Regression model (SUR), Box-Cox Regression model with control function, Household Food Insecurity Access Scale (HFIAS), Multivariate probit model, count data model/ GLM correlation were employed to attain the objectives.

The study's findings, along with existing literature, indicate that smallholder farmers continue to face challenges from climate change, which diminishes and hinders the improvement of their production and income. The results also suggest that socio-demographic factors contribute to influencing crop productivity and income within the food supply chain. This highlights the need to improve these factors, as it could enhance the overall conditions of smallholder farmers in KwaZulu Natal. The study further maps key vulnerabilities in the local food supply chain, including input access, credit limitations, and market disruptions issues that have been exacerbated by both climate stressors and socioeconomic barriers. These insights allow for the formulation of evidence-based policy recommendations, such as enhancing training services, tailoring credit access, and improving infrastructure for irrigation and input delivery.

By filling the empirical gap on climate change impacts specific to vegetable farming, this research advances the academic discourse on climate adaptation in South African agriculture. It also provides actionable guidance for policymakers and development practitioners seeking to improve the resilience of smallholder farmers, thus contributing to broader goals of food security, poverty reduction, and sustainable rural development in the face of a changing climate.

The study hypothesized that climate change impacts the food supply chain of the smallholder farmers in KwaZulu Natal. The hypothesis was accepted, as various analyses conducted in this study revealed that factors influencing crop production and market participation/income had both positive and negative effects on smallholder farmers' livelihoods and food security status. This indicates that further initiatives are necessary to enhance, regulate, and monitor the rapidly changing environment in which smallholder farmers operate.

8.2. Conclusion

This study highlights the profound and multifaceted effects of climate change on smallholder vegetable farmers in KwaZulu Natal, South Africa, revealing both critical challenges and actionable opportunities for building agricultural resilience and food security. Climate variability, manifesting through erratic rainfall, rising temperatures, and extreme weather events, has significantly disrupted crop yields, degraded food quality, and strained supply chains. These disruptions have compounded existing vulnerabilities, deepening food insecurity and economic instability among smallholder farmers.

Importantly, the findings suggest that socio-demographic and agroecological variables shape both the perception and implementation of adaptation strategies. While factors like education,

land ownership, and scale of vegetable production enhance climate change awareness and promote adaptive behaviors, others, such as larger household sizes, insecure tenure, and poor access to farmer networks—dampen resilience. Moreover, systemic issues such as an aging farming population, reliance on rain-fed agriculture, market isolation, and input scarcity further limit farmers' capacity to cope with climate shocks.

Yet, smallholder farmers have demonstrated considerable awareness of the threats posed by climate change, and a willingness to adapt. This presents a valuable opportunity for South Africa's national and provincial governments to design inclusive, forward-thinking adaptation policies that center the realities of smallholder farmers in food system planning.

These findings underscore the urgent need to mainstream smallholder inclusion into South Africa's broader climate adaptation and agricultural development frameworks. Future policy must be designed with a systems-thinking approach that integrates smallholder needs across sectors, including land reform, education, extension services, credit access, and infrastructure development. For example:

- Climate-smart infrastructure (e.g., irrigation systems and storage facilities) can reduce rain-fed dependency and post-harvest losses.
- Tailored financial instruments and climate information services can enable timely, informed decision-making at the farm level.
- Strengthening market linkages and cooperatives can increase farmer incomes while enhancing local food availability and affordability.

In essence, this study affirms that adaptation cannot be treated as a one-size-fits-all technical fix. It must be locally grounded, socially sensitive, and economically viable. The integration of smallholder perspectives into the formulation and implementation of climate policies is not just a matter of justice, it is a strategic necessity for achieving national food security, poverty reduction, and sustainable development under a changing climate.

8.3. Recommendations and policy implications

Based on the findings of this study, a range of interconnected and context-specific recommendations is proposed to enhance the resilience of smallholder vegetable farmers in KwaZulu-Natal and contribute to South Africa's broader climate adaptation agenda. These recommendations consider the socioeconomic vulnerabilities identified in the research, the

urgent need for improved food system integration, and the realities of resource constraints. They also outline the key stakeholders responsible for implementation, ensuring that efforts are collaborative and appropriately targeted.

Firstly, enhancing agricultural extension services should be prioritized. The study found that education level and access to information strongly influence the adoption of climate adaptation strategies. Tailored outreach programs, especially for aging farmers and those with limited formal education, are essential to improve technical efficiency and promote sustainable practices. Local government departments, particularly provincial agricultural offices under the Department of Agriculture, Land Reform and Rural Development (DALRRD), should take the lead in designing and delivering context-appropriate training modules. Support from NGOs such as agricultural development organizations and universities can further bolster the capacity of extension agents and help ensure delivery is participatory and inclusive.

Secondly, supporting the formation and strengthening of farmer cooperatives is critical to improving market access and reducing smallholder reliance on intermediaries. As market participation was found to be a key determinant of income and food access, collective bargaining through cooperatives can enhance smallholders' ability to negotiate better prices and input costs. Local municipalities, NGOs (e.g., Heifer International, Lima Rural Development Foundation), and community-based organizations should facilitate the development of these cooperatives, providing initial training and linking them with buyers and support services. The private sector, particularly agricultural input suppliers and food retailers, should also be engaged to develop inclusive procurement models.

A third recommendation is to promote low-cost, climate-smart agricultural practices. This includes encouraging the use of drought-resistant crop varieties, rainwater harvesting, mulching, and intercropping, practices that are both affordable and effective in reducing climate-related risks. Implementation should be led by local government with technical input from research institutions such as the Agricultural Research Council (ARC) and support from NGOs experienced in sustainable agriculture. These practices can be introduced during extension training sessions and supported through demonstration plots and farmer field schools.

In addition, improving access to microfinance and insurance is essential to reduce vulnerability to shocks and improve investment in adaptation. Many smallholders struggle to afford inputs or recover from crop losses, limiting their adaptive capacity. NGOs, microfinance institutions

such as FinMark Trust, and private insurers should collaborate with national government agencies to design inclusive financial products tailored for rural farmers. These could include low-interest microloans, group-based savings schemes, and weather-indexed insurance products. The South African Reserve Bank and National Treasury could support this through regulatory frameworks that encourage rural financial inclusion.

As part of a medium-term strategy, investment in rural market infrastructure should be prioritized to reduce post-harvest losses and logistical bottlenecks. Cold storage facilities, small-scale processing units, and improved rural road networks would significantly enhance food system efficiency and farmer profitability. This recommendation falls under the remit of local and provincial governments, with support from the Department of Public Works and Infrastructure. Partnerships with private logistics and agribusiness companies can also be explored through public–private partnerships (PPPs), especially where state resources are limited.

To ensure long-term sustainability, formal integration of smallholder farmers into national and regional supply chains must be promoted. Encouraging contract farming arrangements, digital market platforms, and certification schemes can ensure consistent demand and fair prices for farmers. The private sector—especially supermarkets, processors, and tech platforms—must take a proactive role here, working in collaboration with DALRRD and the Department of Trade, Industry and Competition (DTIC) to ensure inclusive value chain development.

Finally, for more advanced and well-resourced interventions, investments in controlled-environment agriculture, such as greenhouses and vertical farming systems, should be piloted. These systems can significantly reduce dependence on erratic rainfall and improve year-round productivity. While these technologies are capital-intensive, they can be introduced gradually in high-risk zones through pilot projects led by the national government in partnership with private technology firms and academic institutions. Where feasible, international donors and development finance institutions could provide startup funding or technology transfer agreements.

Together, these recommendations highlight a phased, stakeholder-driven approach that balances immediate needs with long-term resilience building. By explicitly including smallholder farmers in the planning and implementation of these interventions, South Africa can make meaningful progress towards an inclusive and climate-resilient food system.

8.4. Limitations of the study and suggestions for further research

The study's scope was limited to KwaZulu-Natal province, suggesting an opportunity for future research to compare findings across South Africa's nine provinces. Additionally, while this research focused on smallholder farmers, future studies could assess climate change impacts across different farming sectors, including commercial and subsistence farming. The study focused on vegetable farming, which is often overshadowed by research on staple crops like maize, thus making the study original.

A notable limitation was the study's focus on registered farmers with local agricultural organizations and market operators. While these farmers typically share characteristics with the broader farming community, the findings may not fully represent unregistered smallholder farmers. Future research should include unregistered farmers to provide a more comprehensive understanding of the sector.

Expanding this research to all nine provinces would provide a more complete understanding of these issues, potentially informing government policy and stakeholder initiatives at a national level. Comparative studies should be conducted not only with other provinces but neighbouring countries, to understand the broader patterns and contextual specificities. Such comprehensive research could help develop more effective strategies to enhance smallholder farmers' resilience to climate change and promote sustainable farming practices across South Africa.

APPENDIX A: ETHICAL CLEARANCE LETTER



17 August 2023

Merishca Naicker (214504745)
School Of Agri Earth & Env Sc
Pietermaritzburg Campus

Dear M Naicker,

Protocol reference number: HSSREC/00005925/2023

Project title: An assessment of the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu-Natal Province.

Degree: PhD

Approval Notification – Expedited Application

This letter serves to notify you that your application received on 28 July 2023 in connection with the above, was reviewed by the Humanities and Social Sciences Research Ethics Committee (HSSREC) and the protocol has been granted **FULL APPROVAL**.

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number. **PLEASE NOTE:** Research data should be securely stored in the discipline/department for a period of 5 years.

This approval is valid until 17 August 2024.

To ensure uninterrupted approval of this study beyond the approval expiry date, a progress report must be submitted to the Research Office on the appropriate form 2 - 3 months before the expiry date. A close-out report to be submitted when study is finished.

HSSREC is registered with the South African National Health Research Ethics Council (REC-040414-040).

Yours sincerely,



Professor Dipane Hlalele (Chair)

/dd

Humanities and Social Sciences Research Ethics Committee

Postal Address: Private Bag X54001, Durban, 4000, South Africa

Telephone: +27 (0)31 260 8350/4557/3587 Email: hssrec@ukzn.ac.za Website: <http://research.ukzn.ac.za/Research-Ethics>

Founding Campuses: ■ Edgewood ■ Howard College ■ Medical School ■ Pietermaritzburg ■ Westville

INSPIRING GREATNESS

APPENDIX B: QUESTIONNAIRE



Title: An assessment of the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal province.

The information captured in this questionnaire is strictly confidential and will be used for research purposes by staff and students at the University of KwaZulu-Natal to assess the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal province. Your participation is voluntary, and you are not obliged to answer any questions that you are uncomfortable with. Please provide accurate and honest responses.

Survey number: **Date:**

Name & Surname of respondent:

.....

Section A: Demographics.

Please circle the answer

Name of farm:	
1.1. Gender of respondent	1. Male 2. Female
1.2. Age of the respondent	
1.3. Education level	1. No formal schooling 2. Primary 3. Secondary 4. Tertiary & above
1.4. Marital Status	1. Single 2. Married 3. Divorced 4. Widowed
1.5. What is Your position in your household	1. Household Head 2. Spouse to Household Head 3. Sister 4. Brother 5. Daughter 6. Son 7. Other (Specify)

1.6. What is your household size	
1.7. Are you farming	1. Yes 2. No
1.8. What kind of food production or other agricultural activities is the household involved in? 1 = Livestock production (e.g. cattle, goats, sheep, pig, etc.) 2 = Poultry production (e.g. chicken, ducks, geese, etc.) 3 = Game farming 4 = Grains (maize, wheat, sorghum, millet) 5 = Pulses (beans, groundnuts, cowpea) 6 = Industrial crops (e.g. tea, coffee, cotton, tobacco) 7 = Fruits (e.g. mangos, oranges, peaches) 8 = Vegetable production (e.g. cabbage, spinach, carrots, cucumber) 9 = Fodder, grazing/pasture for grass animals 10 = Fish farming/aquaculture 11 = Forestry 12 = Fishing 13 = Hunting 14 = Other (specify) _____	
1.9. What is the number of years that you have been farming vegetables for?	
1.10. What type of farming do you do?	1. Fulltime 2. Part-time
1.11. Is farming your main source of income?	1. Yes 2. No If no state your main source of income that you depend on.....

1.12. Total income in Rands the last 6 weeks received from farming.

Vegetables produced by smallholder farmer.

Name of Vegetable	Vegetables produced (Kg)	vegetables sold (Kg).	Price per Kg.	vegetables Consumed (Kg).	Vegetables gifted (Kg)
1.					

2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					

Inputs used	Quantity of inputs	Cost of inputs
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		

12.		
13.		

1.13. Total cost of inputs for the last 6 weeks

Inputs used by smallholder farmer in the last 6 weeks.

Agricultural production.

1.2.1 What is the size of the total land owned (Hectares)?	
1.2.2. What is the size of the land used for vegetable production (Hectares)?	
1.2.3. What type of soil do you have?	<ul style="list-style-type: none"> 1. Sandy soil 2.Silt soil 3.Clay soil 4.Loam soil
1.2.4. What is your main source of water for irrigation?	<ul style="list-style-type: none"> 1. Tap 2. River 3. Dam 4. Borehole 5. Rainfed 6. Other (Specify)

1.3.1. Are you a member of	<ul style="list-style-type: none"> 1. Farmers association 2. Cooperations 3. Other (Specify) 4. None
1.3.2. If you are a member of a farmers' association or cooperation, is it	<ul style="list-style-type: none"> 1. Helpful 2. Not helpful 3. Not applicable

Section B: To study the food supply chain in KwaZulu Natal using Supply chain Mapping.

3.1.Are you involved in any formal or informal food supply chain networks or associations?

1=Yes	2=No

3.2. Are you involved in any formal or informal food supply chain networks or associations?

1= Yes, I am part of a cooperative.	2= Yes, I am part of a market association.	3= Yes, I am part of other relevant organizations.	4= No, I am not involved in any such networks or associations.

3.3. Where do you primarily sell your produce?

1= Local markets	2= Middlemen (local distributors)	3= Local stores	4= Chain stores	5= Restaurants	6= bulk market	7= Other (Specify)

3.4. Do you have direct contact with the end consumers of your produce, or do you typically sell through intermediaries?

1= Direct contact with consumers	2= Through intermediaries	3= Both

3.5. Which intermediaries or agents are involved in the supply chain for your produce?

1= Middlemen	2= Retailers	3= Transporters	4= processor	5= Market agents	6= Other (Specify)	7= None

3.6. How do you transport your produce to the market or consumers?

1= Self-transportation	2= Hire transport services	3= Other (Specify)

3.7. Do you experience any challenges related to transportation or logistics when moving your produce to market?

1= Yes	2= No

3.8. If yes, please describe the transportation-related challenges you face.

2.9. Are there specific seasons or times of the year when you experience challenges in getting your produce to market?

1=Yes	2=No

2.10. How do you ensure the quality and freshness of your produce during transportation and distribution?

1= Proper packaging	2= Temperature-controlled storage	3= Quick delivery to market	4= Quality checks before transportation	5= Other (specify)	6= I do not take specific measures to ensure quality and freshness

2.11. Are you satisfied with the prices you receive for your produce in the current supply chain?

1= Very satisfied	2= Satisfied	3= Neutral	4= Dissatisfied	5= Very dissatisfied

2.12. Do you feel that the existing food supply chain adequately serves the interests and needs of smallholder vegetable farmers like yourself?

1=Yes	2=No

2.13. Are you aware of any policies or regulations governing the food supply chain that affect your operations?

1=Yes	2=No

Section C: To evaluate the impact of climate change on the income share of smallholder vegetable farmers in rural KwaZulu Natal Province.

3.1. Have you experienced low vegetable yields over the past 10 years?

1= Yes	2= No	3=Don't Know
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--	--	--

If answered No, Skip to question 3.5.

3.2. How severe has the loss been over the past 10 years?

1= Very severe	2= Moderately severe	3= Not severe	4= Don't Know	5= Other (Specify)

3.3. What do you think where the causes of the yield decline?

1=Natural causes (droughts, hails, floods)	2= Pest damage	3=Disease outbreak	4= Lack of farm inputs	5= Lack of water	6=Don't know

Other specify.....

3.4. How did you adapt to those changes?

1= Applied indigenous Knowledge	2= Assistance of Extension officers	3= Didn't do anything	4= Don't know	5=Other (Specify)

3.5. What is the main impact that you feel climate change has?

1= Crop failure	2= Food insecurity	3= Don't know	4= Other (specify)

3.6.1. Do you feel that the planting seasons have changed due to climate change?	1= Yes 2= No 3=Don't know
3.6.2. Have the planting seasons become	1= Longer 2= Shorter 3=Don't know
3.6.3. Have the change in seasons affected your vegetable production	1= positively 2= Negatively 3=Don't know
3.6.4. Do you feel that climate change has changed the productivity of your land over the years	1= Yes 2= No 3=Don't know
3.6.5. How has the change affected your productivity	1= Increased 2= Decreased 3=Don't know

3.6.6. Has there been increased pest and diseases	1= Yes 2= No 3=Don't know
3.6.7. Has there been a change in your soil	1= Yes 2= No 3=Don't know
3.6.8. Do you think that the increase in soil, pest and diseases are caused by climate change?	1=Yes 2= No 3=Don't know

3.7.1. Where do you sell your produce?	1. Local municipal market 2. Middleman (local distributors) 3. Local stores 4. Chain stores 5. Restaurants 6. Other (Specify)
3.7.2. How often do you supply produce a week?	
3.7.3. Do you transport your produce by yourself?	1. Yes 2. No 3. Don't know
3.7.4. Have you experienced loss of vegetables?	1. Yes 2. No 3. Don't know
3.7.5. Is the loss of vegetables incurred?	1. Significant 2. Insignificant 3. Don't know
3.7.6. Has the loss of vegetables been due to?	1. Drought 2. Floods 3. Rot 4. Insects/pest 5. Transport damage to market 6. Not applicable
3.7.7. Do you recover from the loss incurred?	1. Yes 2. No 3. Don't know
3.7.8. In the last 5 years has your food availability	1. Increased 2. Decreased 3. Don't know
3.7.9. In the last 5 years has your sales	1. Increased 2. Decreased 3. Remained unchanged
3.7.10. Do you have access to market information (e.g., market prices, when to grow, where to sell)?	1. Yes 2. No 3. Don't know
3.7.11. Were you able to meet the demand of the market in the last 5 years?	1. Yes 2. No 3. Don't know

3.8. How do you select the crop (s) to grow? (Rank levels of reason in the second column – 1– 8 or 1-9 if specified other reason)

	Reason	Rank
1	Resistance to drought	
2	Early maturity	
3	Resistance to disease	
4	High yield potential	
5	Human consumption	
6	Easy management of crop	
7	Easy market access	
8	Not applicable	
9	Other (Specify)	

3.9. What other services do you wish to access to improve your vegetable production? (Indicate all that apply in order of importance from 1-7)	
Market information	
Market linkage	
Advisory services	
Savings and/or Credit facilities	
Processing facilities	
Agriculture skills training	
Production inputs	
* 1 for the most important and 7 for the least important. The range of values is between 1 to 7	

3.10. Crop Yields

3.10.1. How do you normally measure your crop yields? (you can select multiple options)

- a) In bags
- b) Dozens
- c) In containers
- d) In Kg's
- e) All of the above
- f) Other (Specify)

3.10.2. How much yields did you obtain this season of each crop planted ? Specify units.....

.....

.....

.....

.....

.....

.....

3.10.3. How much do you sell each unit for?.....

3.10.4. How much did you sell and how much was consumed by your household (Ratio)?.....

3.10.5. Was your crop affected by the following natural disasters?

Natural Disaster	Yes	No
Drought		
Pest		
Diseases		
Hail storm		
Heavy rains/Floods		
Livestock trampling		
Soil infertility		
Other (Specify)		

3.10.6. If this seasons yield was affected by a natural disaster, what are the normal yields that you get? (specify units).....

3.10.7. How would you rate the yield you obtained this season in comparison to your normal yield?

Very low				Very high
1	2	3	4	5

3.10.8. What is the best yield that you could get on your farm using the best crop production practices in a normal rainfall year? (specify units).....

-

- 3.10.9. What is the worst yield you could get without using an recommended farming practices on your farm?.....

- 3.10.10.If your yield of crop this year was what you stated above, what are you striving for next season? (specify units).....

- 3.10.11.How can you improve your farming to reach your goal in terms of crop yield?.....

- 3.10.12.How to you intend to cope with the natural disasters mentioned in question 3.10.5?.....

Section D: The perceptions of climate change on food security by the smallholder farmers.

4.1.1. Do you understand what climate change is?	1. Yes 2. No 3. Don't know
4.1.2. Do you receive information on Climate Change?	1. Yes 2. No 3. Don't know
4.1.3. What is your main source of information on climate change?	1. Newspaper 2. Weekly magazine

<p>(You can choose multiple options.)</p>	<ol style="list-style-type: none"> 3. Internet (e.g. google) 4. Radio 5. Television 6. Neighbours 7. Health workers 8. Teachers 9. Extension officers 10. Family members/relatives/friends 11. NGO workers 12. Personal involvement in Training 13. Personal involvement in environmental protection 14. Other (Specify) _____
<p>4.1.4. What are the primary causes and reasons for climate change (You can choose multiple options.)</p>	<ol style="list-style-type: none"> 1. Deforestation 2. Land use changes 3. Use of chemical fertilizers 4. Agricultural practices 5. Soil degradation 6. Water resource management 7. Pesticide use 8. Livestock emissions 9. Crop choices 10. Land clearing for farming 11. Other (Specify) _____ 12. I don't know
<p>4.1.5. Has climate change happened in your local region?</p>	<ol style="list-style-type: none"> 1. Yes 2. No 3. Uncertain
<p>4.1.6. Types of change in climate that occurred in your region.</p>	<ol style="list-style-type: none"> 1. Excessive temperatures 2. Excessive cold

	3. Change of pattern in rainfall 4. Frequent floods 5. Waterlogging 6. Don't know/don't understand
4.1.7. Do you think that climate change is important	1. Very important 2. Important 3. Not very important 4. Not important at all
4.1.8. Do you think anything can be done about climate change?	1. Yes 2. No 3. I don't know

4.2. Each of the following questions consider what has happened in the **past 20 years**. Please answer whether this happened never, rarely, sometimes, or often? (*tick the appropriate answer*)

Event		Frequency of event			
		Never (0 times)	Rarely (1-2 times)	Sometimes (3-4 times)	Often > 4 times
4.2.1.	Did you worry that your household would face recurrent flood?				
4.2.2.	Did you worry that your household would face recurrent drought?				
4.2.3.	Did you worry that your household would face crop disease?				
4.2.4.	Did you worry that your household would face crop failure other than from drought?				
4.2.5.	Did you worry that your household would face price decline for your produce?				
4.2.6.	Did you worry that your household would face soil fertility decline?				
4.2.7.	Did you worry that your household would face price increase for your inputs?				

4.2.8.	Did you worry that your household would face shorter rainy season?				
4.2.9.	Did you worry that your household would face late on set of rain?				
4.2.10.	Did you worry that your household would face climate variability?				

4.3. What impacts has climate change had on food security?

	Strongly agree	Agree	Neither agree nor disagree	Dis-agree	Strongly disagree	(Do not know)
Increased food prices						
Reduced food prices						
Increased income						
Reduced income						
Lack of local markets						
Increased employment						
Decreased employment						
Scarcity of food						
Other (specify)						

4.4 General Household Food Consumption

4.4.1. Frequency of vegetable consumption per month (i.e., number of times vegetables from your own farm was consumed in the last one month)	
4.4.2. Do you prefer vegetables to other food items? Yes=1, No=2	
4.4.3. If your answer in question 2 is No, which food item do you prefer?	
4.4.4. Where do you usually purchase your vegetables? Open market=1, supermarket=2, store, or shop=3, you consume your own produce=4	
4.4.5. Reason(s) for your Vegetable consumption preference(s). Tick appropriately in order of importance from 1 to 7	
(1) Price	
(2) Nutritional quality	
(3) Taste	
(4) Ease of preparation	

(5) Cleanliness	
(6) Colour	
(7) Origin	
4.4.6. What quantity of vegetables do you usually purchase per month in kg?	
4.4.7. how much did you spend on purchasing vegetables in the following years?	
1. 2018	
2. 2019	
3. 2020	

4.4. What is your main source of food in your household?		
1. Own production	2. Purchase	3. Food aid

4.5. How many meals are eaten a day by each family member?				
1	2	3	4	5

4.6. Coping strategy index

Behaviors: In the past 7 days, if there have been times when you did not have enough food or money to buy food, how many days has your household had to:	Frequency: Number of days out of the past seven: (Use numbers 0 – 7 to answer number of days; Use NA for not applicable)
a. Rely on less preferred and less expensive foods?	
b. Borrow food, or rely on help from a friend or relative?	
c. Purchase food on credit?	
d. Gather wild food, hunt, or harvest immature crops?	
e. Consume seed stock held for next season?	
f. Send household members to eat elsewhere?	
g. Send household members to beg?	
h. Limit portion size at mealtimes?	
i. Restrict consumption by adults for small children to eat?	
j. Feed working members of HH at the expense of non-workingmembers?	
k. Reduce number of meals eaten in a day?	
l. Skip entire days without eating?	

4.7. HOUSEHOLD FOOD INSECURITY ACCESS SCALE

No	Question	Response Options	Answer
----	----------	------------------	--------

4.9.1.	In the past four weeks, did you worry that your household would not have enough food?	0= No (skip to Q2) 1= Yes	
4.9.1. a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2=Sometimes (three to ten times in the past four weeks) 3=Often (More than ten times in the past four weeks)	
4.9.2.	In the past four weeks, were you or any household member not able to eat the kinds of food you preferred because of the lack of resources?	0= No (skip to Q3) 1= Yes	
4.9. a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2=Sometimes (three to ten times in the past four weeks) 3=Often (More than ten times in the past four weeks)	
4.9.3.	In the past four weeks, did you or any household member have to eat a limited variety of food due to lack of resources?	0= No (skip to Q4) 1= Yes	
4.9.3. a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2=Sometimes (three to ten times in the past four weeks) 3=Often (More than ten times in the past four weeks)	
4.9.4.	In the past four weeks, did you or any household member have to eat some foods that you did not want to eat because of the lack of	0= No (skip to Q5) 1= Yes	

	resources to obtain other types of food?		
4.9.4. a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2=Sometimes (three to ten times in the past four weeks) 3=Often (More than ten times in the past four weeks)	
4.9.5.	In the past four weeks, did you or any other household member have to eat a smaller meal than you felt you needed because there was not enough food?	0= No (skip to Q6) 1= Yes	
4.9.5. a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2=Sometimes (three to ten times in the past four weeks) 3=Often (More than ten times in the past four weeks)	
4.9.6.	In the past four weeks, did you or any other household member have to eat fewer meals in a day because there was not enough food?	0= No (skip to Q7) 1= Yes	
4.9.6. a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2=Sometimes (three to ten times in the past four weeks) 3=Often (More than ten times in the past four weeks)	
4.9.7.	In the past four weeks, was there ever no food to eat of any kind in your household because of a lack of resources to get food?	0= No (skip to Q8) 1= Yes	

4.9.7. a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2=Sometimes (three to ten times in the past four weeks) 3=Often (More than ten times in the past four weeks)	
4.9.8.	In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?	0= No (skip to Q9) 1= Yes	
4.9.8. a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2=Sometimes (three to ten times in the past four weeks) 3=Often (More than ten times in the past four weeks)	
4.9.9.	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?	0=No (the questionnaire is finished) 1= Yes	
4.9.9. a	How often did this happen?	1= Rarely (once or twice in the past four weeks) 2=Sometimes (three to ten times in the past four weeks) 3=Often (More than ten times in the past four weeks)	

Section E: To determine the factors influencing the choice and level of adaptation strategies among smallholder vegetable farmers.

- a. Have you experienced a decrease in overall crop productivity due to climate variability?

1=Yes	2= No	3= Don't know

If, in your view, overall crop productivity is decreasing, especially because of climate variability, do you use the following adaptation strategies to cope with this adverse situation? **(Tick either yes or no below)**

	Yes	No
i. Crop diversification		
5.1.2. Growing different crop varieties		
5.1.3. Diversifying farming to non-farming activities		
5.1.4. Intercropping		
5.1.5. Cover cropping		
5.1.6. Crop residue management		
5.1.7. Minimum tillage		
5.1.8. Different fields planted at different times		
5.1.9. Annual crop rotation		
5.1.10. Practice mulching		
5.1.11. Across slope cultivation		
5.1.12. Use of organic manure		
5.1.13. Fields are left fallow		
5.1.14. Tree planting alongside crops		
5.1.15. Rainwater harvesting for irrigation		
5.1.16. Application of chemical fertilizers		
5.1.17. Use of moist valley bottom		
5.1.18. Mixed farming		
5.1.19. Changing diet		
5.1.20. Land use extension		
5.1.21. Land use intensification		
5.1.22. Out – migration		
5.1.23. Carrying on as usual		
5.1.24. Lease your land		
5.1.25. Buy insurance		

b. If, you do not use certain adaptations, please tick the reason why from the list below.

	Lack of money	Lack of motivation	Shortage of labour	Bad method	Other (Specify)
5.2.1. Crop diversification					
5.2.2. Growing different crop varieties					
5.2.3. Diversifying farming to non-farming activities					
5.2.4. Intercropping					
5.2.5. Cover cropping					

5.2.6. Crop residue management					
5.2.7. Minimum tillage					
5.2.8. Different fields planted at different times					
5.2.9. Annual crop rotation					
5.2.10. Practice mulching					
5.2.11. Across slope cultivation					
5.2.12. Use of organic manure					
5.2.13. Fields are left fallow					
5.2.14. Tree planting alongside crops					
5.2.15. Rainwater harvesting for irrigation					
5.2.16. Application of chemical fertilizers					
5.2.17. Use of moist valley bottom					
5.2.18. Mixed farming					
5.2.19. Changing diet					
5.2.20. Land use extension					
5.2.21. Land use intensification					
5.2.22. Out-migration					
5.2.23. Carrying on as usual					
5.2.24. Lease your land					
5.2.25. Buy insurance					

6.3. CLIMATE SMART AGRICULTURAL PRACTICES			
	PRACTICES	Yes	No
A	KNOWLEDGE SMART		
1	Get access to information of market prices of produce & inputs		
2	Store seeds for emergency/ next season (seed banking)		
3	Belong to farmer associations		

4	Have a backyard garden in addition to your farm		
5	Share one -on- one information with colleagues (farmer-to-farmer knowldege sharing)		
B	CARBON SMART		
1	Plant trees in and around your farm (afforestation)		
2	Change the type of crop planted on the land in some seasons (Crop rotation)		
3	Use animal and plant manure on your farm (Organic manuring)		
4	Use less heavy equipment on your farms (minimum tillage)		
5	Plant different type of crops together (Mix cropping)		
C	NITROGEN SMART		
1	Plant legumes among crops		
2	Estimate the amount of manure/fertilizer needed at a time (precision fertilization)		
3	Use specific manure/fertilizer based based on the type of soil (Site specific nutrient application)		
D	WATER SMART		
1	Havest and store rainwater to be used on your farm		
2	Plant early in the season to make use of rain water		
3	Plant cover crops to maintain soil moisture		
4	Regulate/control the water used in watering crops		
5	Engage in mulching to reduce excessive use of water		
E	WEATHER SMART		
1	Received weather information through community information centre		
2	Access to weather information on the internet		
3	Use mobile phone to access weather information		
4	Usage of TV/radio for weather information		
5	Take index- based Insurance (IBI) to protect your farm		
6	Received training/education on how to access weather information by an orgainsation		
7	Use personal expereince to predict weather events		
F	ENERGY SMART		
1	Convert your residue into bioenergy		
2	Use of less fuel consuming vechiles		
3	Compost your residue after haversting		
4	Use solar equipment in farming		

Thank you for your participation and time!

APPENDIX C: KEY INFORMATIVE INTERVIEWS



KEY INFORMANT INTERVIEW

Title: An assessment of the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu- Natal province.

The information captured in this Key informant interview is strictly confidential and will be used for research purposes by staff and students at the University of KwaZulu-Natal to assess the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal province. The respondents are not forced to answer questions – the answers are strictly voluntary. The respondent should be a market agent / middleman. For smallholder farmerin KwaZulu Natal.

Consent Process

Consent forms for Key informant interview participants are completed in advance by all those seeking to participate. Below is a summary of the information in the consent form that key informant interview organizers should use to ensure participants understand the information in the consent form.

Thank you for agreeing to participate. We are very interested in hearing your valuable opinion on the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal province.

1. The purpose of this study is to assess the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal province.
2. The information provided by you is entirely confidential, and we will not associate your name with anything you say in the key informant interview.
3. we would like to record the Key informant interview to ensure that we correctly capture the group's thoughts, opinions, and ideas. No names of participants will be attached to the key informant, and the recordings will be destroyed as soon as they are transcribed.
4. You can choose not to answer any question and withdraw from the study at any time.

5. We understand the importance of keeping the information provided by the participants private and confidential. Therefore, we will ask participants to respect each other's confidentiality.

Introduction:

1. Welcome-Introduce yourself. Review the following:
 6. Who we are and what we're trying to do
 7. How this information will be utilized
 8. Why we asked you to participate

Explanation of the process

Ask if the informant has participated in a key informant

interview before. About key informant interview:

9. We learn from you (positive and negative)
10. Not trying to achieve consensus, we're gathering information
11. In this project, we are doing questionnaires, focus group discussions, and key informant interviews. Using this tool, we can get an in-depth view about the issues associated with the research. This provides us with an understanding of the context behind the answers given in the questionnaires and focused group discussions.

Logistics

12. Interview would last around 30 min
13. COVID-19 regulations will adhere too

The interview begins, making sure to give the participant time to think before answering the questions and not moving too quickly. Use the probes to ensure that all issues are addressed but move on when you feel you are starting to hear repetitive information.

Questions

- What effect do you feel that climate change is having on the production and quality of produce received by smallholder farmers for sale?
- Has the produce received by smallholder farmers increased or decreased over the last 10 years, and why?
- How have the recent climatic events affected the price of produce by

smallholderfarmers?

- How have recent climatic events affected the sale of produce by smallholderfarmers?
- What impact has these recent events had on your income?
- What do you feel can be done to help smallholder farmers increase their production with minimal loss?
- Has the shelf life of the produce increased or decreased over the last 10 years, and what do you think causes this?
- What do you do with your food waste, when it cannot be sold?
- Have you seen a reduction or increase in the number of smallholder suppliers overthe last 10 years, and why?
- Have you seen a reduction or increase in the number of buyers over the last 10 years,and why?
- Do you think that these climatic changes are having a positive or negative impacton the food supply and food security status of the province? And why?
- Any additional comments?

Thank you for your time and participation

APPENDIX D: FOCUSED GROUP DISCUSSIONS



APPENDIX C: FOCUSED GROUP DISCUSSION

Title: An assessment of the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal province.

The information captured in this focused group discussion is strictly confidential and will be used for research purposes by staff and students at the University of KwaZulu-Natal to assess the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal province. The respondents are not forced to answer questions – the answers are strictly voluntary. The respondent should be a smallholder farmer in KwaZulu Natal.

Consent Process

Consent forms for focus group participants are completed in advance by all those seeking to participate. Below is a summary of the information in the consent form that focus group organizers and facilitators should use to ensure participants understand the information in the consent form.

Thank you for agreeing to participate. We are very interested in hearing your valuable opinion on the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers.

- The purpose of this study is to assess on the impact of climate change on food supply chain and livelihoods of smallholder vegetable farmers in rural KwaZulu Natal province.
- The information provided by you is entirely confidential, and we will not associate your name with anything you say in the focus group.
- we would like to record the focus group discussions to ensure that we correctly capture the group's thoughts, opinions, and ideas. No names of participants will be attached to the focus groups, and the recordings will be destroyed as soon as they are transcribed.
- You can choose not to answer any question and withdraw from the study at any time.
- We understand the importance of keeping the information provided by the participants private and confidential. Therefore, we will ask participants to respect each other's confidentiality.

Introduction:

1. Welcome

Introduce yourself and the note-taker and send the Sign-In Sheet with a few quick demographic questions (age, gender) around to the group while you are introducing the focus group.

Review the following:

- Who we are and what we're trying to do
- How this information will be utilized
- Why we asked you to participate

2. Explanation of the process

Ask the group if anyone has experienced in a focus group before. Explain that focus groups are being used more and more often in research.

About focus groups:

- We learn from you (positive and negative)
- Not trying to achieve consensus, we're gathering information
- In this project, we are doing questionnaires, focus group discussions, and key informant interviews. Using these tools is that we can get more in-depth information from a smaller group of people in focus groups. This provides us with an understanding of the context behind the answers given in the written survey and helps us discover topics in more detail than we can do in a written survey.

Logistics

- Focus group will last about one hour
- Feel free to move around
- Where is the bathroom? Exit?

- COVID-19 regulations will adhere too
 - Mask must always be worn, and sanitizer will be provided.
 - Social distancing will be obeyed.

3. **Ground Rules**

Ask the group to suggest some ground rules. After they brainstorm some, make sure the following are on the list.

- Everyone should participate.
 - Information provided in the focus group must be kept confidential.
 - Stay with the group and please do not have side conversations.
 - Turn off cell phones if possible.
 - Have fun.
4. Turn on Tape Recorder
 5. Ask the group if there are any questions before we get started and address those questions.
 6. Introductions
 - Go around the table: where you were born etc.

The discussion begins, making sure to give people time to think before answering the questions and not moving too quickly. Use the probes to ensure that all issues are addressed but move on when you feel you are starting to hear repetitive information.

Questions

1. What do you understand by climate change?
2. What are some of the problems that your farm faces regarding climate change and do you feel that climate change is an issue?
3. How do you overcome these challenges?
4. What help do you receive and from where regarding the issues of climate change?
5. Is the help provided useful to you?
6. What challenges has climate change factors imposed on your market supply?
7. How has these challenges affected your sales and income?
8. Have you been able to meet the demand of the markets within the last year?
9. What adaption measures have you put in place to meet the market needs?
10. Are you happy with the profit margin that you make from the markets?
11. Are the market agents a benefit to you, and what are some of the challenges you face regarding these agents?
12. Do you think that our food security status as a country is at a risk, and how can we overcome it?
13. Additional questions and comments

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Thank you for your time and participation!



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YAKWAZULU-NATALI

SEASONALITY CHART

Types of vegetables	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Herbs												
Pumpkin												
Mealies												
Sweet potato												
Sugar beans												
Blackjack												
Brinjal- eggplant												
Calabash												
Chilies												
Coriander (dhania)												
Green beans												
Basil												
Curry leaves												
Mint												
Cabbage												
Spinach												
Yams- madumdi												
Tomatoes												
Potatoes												
Carrot												

Onion												
Bhindi-okra												
Butternut												
Double beans												

KEY:

- - PLENTY
- - ENOUGH
- - VERY LITTLE
- - NO FOOD

APPENDIX E: SUPPLEMENTARY TABLES FOR THE SYSTEMATIC REVIEW.

Table 1: Scoping review screening records

Date	Database	Search string	Retrieved articles	Eligible articles
11/04/2023	Web of Science	TITLE-ABS-KEY (climate AND change AND food AND supply AND chain AND agriculture OR <i>smallholder</i> AND <i>farmers</i> OR <i>adaptation</i> AND <i>strategies</i> OR <i>livelihoods</i> OR <i>food</i> AND <i>security</i> OR <i>resilience</i>) AND (LIMIT-TO (LANGUAGE, "English"))	27,249	26
14/03/2023	Scopus	climate AND change AND food AND supply AND chain AND agriculture OR smallholder AND farmers OR adaptation AND strategies OR livelihoods OR food AND security OR resilience AND PUBYEAR > 1992 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (PUBSTAGE, "final"))	7,232	20
16/04/2023	Google scholar	Climate Change AND Food Supply Chain AND Agriculture OR Smallholder Farmers OR Adaptation Strategies OR Livelihoods OR Food Security Resilience. The search was refined to articles published in English, and between the period of 1993-2023.	20,500	97
	Subtotal		54,981	143

Table 2: Web of Science results after being limited to inclusion/exclusion criteria

Date	Database	Key themes	Retrieved articles	Eligible articles
11/04/2023	Web of science	Climate change	166	20
		agricultural policy	43	3
		soil science	36	0
		environmental science	18	1
		sustainability science	16	0
		management science	14	0
		supply chain & logistics	11	2
		human geography	10	0
		crop science	8	0
		herbicides, pesticides & ground poisoning	5	0
		economics	2	0
Subtotal:			329	26

Table 3: Characteristics of studies included in the review from Scopus

	Author and Year	Title	Reason for inclusion	Link
1.	AWAN, S., AHMED, S., ULLAH, F., NAWAZ, A., KHAN, A., UDDIN, M. I., ALHARBI, A., ALOSAIMI, W., & ALYAMI, H. (2021).	IoT with Blockchain: A Futuristic Approach in Agriculture and Food Supply Chain. <i>Wireless Communications and Mobile Computing</i> , 2021.	Explores the use of IoT and blockchain in agriculture, crucial for increasing transparency and efficiency in food supply chains.	https://doi.org/10.1155/2021/5580179
2.	BEZARES, A., N., FRETES, G., & MARTINEZ, E. M. (2021).	The Role of Food and Beverage Companies in Transforming Food Systems: Building Resilience at Multiple Scales. <i>Current Developments in Nutrition</i> , 5(9) 2021.	Examines corporate roles in food systems resilience, relevant to sustainable transformations.	https://doi.org/10.1093/cdn/nzab110
3.	DINESH, D., HEGGER, D. L. T., KLERKX, L., VERVOORT, J., CAMPBELL, B. M., & DRIESSEN, P. P. J. (2021).	Enacting theories of change for food systems transformation under climate change. <i>Global Food Security</i> , 31.	Addresses strategies for transforming food systems in the face of climate change, valuable for policy and planning.	https://doi.org/10.1016/j.gfs.2021.100583
4.	DUCHENNE-MOUTIEN, R. A., & NEETOO, H. (2021).	Climate change and emerging food safety issues: A review. In <i>Journal of Food Protection</i> (Vol. 84, Issue 11, pp. 1884–1897). International Association for Food Protection.	Discusses how climate change impacts food safety, an emerging area of concern in food security.	https://doi.org/10.4315/JFP-21-141
5.	HANK, T. B., BERGER, K., BACH, H., CLEVERS, J. G. P. W., GITELSON, A., ZARCO-TEJADA, P., & MAUSER, W. (2019).	Spaceborne Imaging Spectroscopy for Sustainable Agriculture: Contributions and Challenges. In <i>Surveys in Geophysics</i> (Vol. 40, Issue 3, pp. 515–551). Springer Netherlands.	Analyzes advanced technology for monitoring agriculture, highlighting contributions to sustainable practices.	https://doi.org/10.1007/s10712-018-9492-0
6.	KING, T., COLE, M., FARBER, J. M., EISENBRAND, G., ZABARAS, D., FOX, E. M., & HILL, J. P. (2017).	Food safety for food security: Relationship between global megatrends and developments in food safety. In <i>Trends in Food</i>	Links food safety with global trends, critical for understanding future food security challenges.	https://doi.org/10.1016/j.tifs.2017.08.014

		Science and Technology (Vol. 68, pp. 160–175). Elsevier Ltd.		
7.	LENGNICK, L., MILLER, M., & MARTEN, G. G. (2015).	Metropolitan foodsheds: a resilient response to the climate change challenge? <i>Journal of Environmental Studies and Sciences</i> , 5(4), 573–592.	Examines regional food systems for resilience, highlighting urban agriculture's role in sustainability.	https://doi.org/10.1007/s13412-015-0349-2
8.	LUO, J., LENG, S., & BAI, Y. (2022).	Food supply chain safety research trends from 1997 to 2020: a bibliometric analysis. <i>Frontiers in Public Health</i> , 9.	A bibliometric analysis, showing shifts in focus on food supply chain safety, relevant for policy adjustments.	https://doi.org/10.3389/fpubh.2021.742980
9.	MANOJ. T, MAKKITHAYA, K., & V.G., N. (2023).	A trusted IoT data sharing and secure oracle-based access for agricultural production risk management. <i>Computers and Electronics in Agriculture</i> , 204.	Focuses on secure data handling in agricultural IoT, crucial for risk management.	https://doi.org/10.1016/j.compag.2022.107544
10.	MEHMOOD, Z., RAZA, A., AHMED, T., IRSHAD, M. A., & KHAN, M. (2022).	Agricultural post-harvest sustainability through the development of Low-Cost Zero Energy Cooling Chambers (ZECC) - A case study of tomatoes. <i>Journal of Global Innovations in Agricultural Sciences</i> , 10(3), 159–164.	Highlights sustainable, low-cost tech for post-harvest processes, essential for reducing losses.	https://doi.org/10.22194/JGIAS/10.987
11.	MEYER, M. A. (2020).	The role of resilience in food system studies in low- and middle-income countries. In <i>Global Food Security</i> (Vol. 24). Elsevier B.V.	Discusses resilience-building in food systems in vulnerable regions, key for sustainability.	https://doi.org/10.1016/j.gfs.2020.100356
12.	MISHRA, A., BRUNO, E., & ZILBERMAN, D. (2021).	Compound natural and human disasters: managing drought and COVID-19 to sustain global agriculture and food sectors. <i>The Science of the Total Environment</i> , 754, 142210.	Evaluates dual challenges (pandemic and drought), important for understanding compound impacts on agriculture.	https://doi.org/10.1016/j.scitotenv.2020.142210

13.	NCHANJI, E. B., LUTOMIA, C. K., CHIRWA, R., TEMPLER, N., RUBYOGO, J. C., & ONYANGO, P. (2021).	Immediate impacts of COVID-19 pandemic on bean value chain in selected countries in sub-Saharan Africa. <i>Agricultural Systems</i> , 188.	Examines pandemic impacts on food value chains, relevant for resilience and recovery insights.	https://doi.org/10.1016/j.agry.2020.103034
14.	PALOVIIITA, A. & JÄRVELÄ, M. (2019).	Multilevel governance for climate change adaptation in food supply chains., 479-496.	Focuses on governance approaches for climate adaptation, vital for integrated food supply chain strategies.	https://doi.org/10.1007/978-3-319-77878-5_23
15.	RAHMAN, M. M., AKTER, R., ABDUL BARI, J. BIN, HASAN, M. A., RAHMAN, M. S., ABU SHOAIB, S., SHATNAWI, Z. N., ALSHAYEB, A. F., SHALABI, F. I., RAHMAN, A., ALSANAD, M. A., & RAHMAN, S. M. (2022).	Analysis of Climate Change Impacts on the Food System Security of Saudi Arabia. <i>Sustainability (Switzerland)</i> , 14(21).	Examines climate change's specific effects on food security in a Middle Eastern context.	https://doi.org/10.3390/su142114482
16.	RAHMAN, M. M., NGUYEN, R., & LU, L. (2022).	Multi-level impacts of climate change and supply disruption events on a potato supply chain: An agent-based modelling approach. <i>Agricultural Systems</i> , 201.	Investigates climate and supply chain shocks, relevant for crop-specific risk analysis.	https://doi.org/10.1016/j.agry.2022.103469
17.	RAMIREZ-VILLEGAS, J., SALAZAR, M., JARVIS, A., & NAVARRO-RACINES, C. E. (2012).	A way forward on adaptation to climate change in Colombian agriculture: Perspectives towards 2050. <i>Climatic Change</i> , 115(3–4), 611–628.	Provides adaptation insights for agriculture in a climate-sensitive region.	https://doi.org/10.1007/s10584-012-0500-y
18.	RASUL, G. (2021).	Twin challenges of COVID-19 pandemic and climate change for agriculture and food security in South Asia. <i>Environmental Challenges</i> , 2.	Discusses compounding challenges to food security in South Asia due to climate and pandemic impacts.	https://doi.org/10.1016/j.envc.2021.100027
19.	SCHERER, L., & VERBURG, P. H. (2017).	Mapping and linking supply- and demand-side measures in climate-smart agriculture. A review. In <i>Agronomy for Sustainable</i>	Reviews climate-smart approaches in agriculture, focusing on mitigation and adaptation strategies.	https://doi.org/10.1007/s13593-017-0475-1

		Development (Vol. 37, Issue 6). Springer-Verlag France.		
20.	SINGH, M., MARCHIS, A., & CAPRI, E. (2014).	Greening, new frontiers for research and employment in the agro-food sector. <i>Science of the Total Environment</i> , 472, 437–443.	Addresses sustainability initiatives in the agro-food industry, focusing on employment and environmental impact.	https://doi.org/10.1016/j.scitotenv.2013.11.078

Table 4: Characteristics of studies included in the review from Web of Science

	Author and Year	Title	Reason for Inclusion	Link
1.	AMICARELLI, V., & BUX, C. (2020).	Food waste measurement toward a fair, healthy and environmental-friendly food system: a critical review. In <i>British Food Journal</i> (Vol. 123, Issue 8, pp. 2907–2935). Emerald Group Holdings Ltd.	Insights into food waste reduction for sustainable food systems.	https://doi.org/10.1108/BFJ-07-2020-0658
2.	AYANLADE, A., OLUWARANTI, A., AYANLADE, O. S., BORDERON, M., STERLY, H., SAKDAPOLRAK, P., JEGEDE, M. O., WELDEMARIAM, L. F., & AYINDE, A. F. O. (2022).	Extreme climate events in sub-Saharan Africa: A call for improving agricultural technology transfer to enhance adaptive capacity. In <i>Climate Services</i> (Vol. 27). Elsevier B.V.	Agricultural adaptation strategies in response to extreme climate events.	https://doi.org/10.1016/j.cliser.2022.100311
3.	BIGLIARDI, B., & FILIPPELLI, S. (2022).	A review of the literature on innovation in the agro Food industry: sustainability, smartness and health. In <i>European Journal of Innovation Management</i> (Vol. 25, Issue 6, pp. 589–611). Emerald Group Holdings Ltd.	Examines sustainability and innovation in food production.	https://doi.org/10.1108/EJIM-05-2021-0258
4.	BROUDER, S. M., & GOMEZ-MACPHERSON, H. (2014).	The impact of conservation agriculture on smallholder agricultural yields: A scoping review of the evidence. In <i>Agriculture, Ecosystems and Environment</i> (Vol. 187, pp. 11–32). Elsevier B.V.	Conservation practices and productivity in small-scale agriculture.	https://doi.org/10.1016/j.agee.2013.08.010

5.	BURNHAM, M., & MA, Z. (2016).	Linking smallholder farmer climate change adaptation decisions to development. In <i>Climate and Development</i> (Vol. 8, Issue 4, pp. 289–311). Taylor and Francis Ltd.	Links adaptation practices to development in small-scale farming.	https://doi.org/10.1080/17565529.2015.1067180
6.	CHANDRA, A., MCNAMARA, K. E., & DARGUSCH, P. (2018).	Climate-smart agriculture: perspectives and framings. <i>Climate Policy</i> , 18(4), 526–541.	Climate resilience and agricultural sustainability practices.	https://doi.org/10.1080/14693062.2017.1316968
7.	CHEN, J., ZHONG, F., & SUN, D. (2022).	Lessons from farmers' adaptive practices to climate change in China: a systematic literature review. In <i>Environmental Science and Pollution Research</i> (Vol. 29, Issue 54, pp. 81183–81197). Springer Science and Business Media Deutschland GmbH.	Adaptation strategies to climate impacts in agriculture.	https://doi.org/10.1007/s11356-022-23449-z
8.	DARDONVILLE, M., URRUTY, N., BOCKSTALLER, C., & THEROND, O. (2020).	Title 1 Influence of diversity and intensification level on vulnerability, resilience and robustness of agricultural 2 systems 3.	Evaluates sustainability and resilience of diverse agricultural systems.	https://www.sciencedirect.com/science/article/am/pii/S0308521X20307745
9.	HECHT, A. A., & NEFF, R. A. (2019).	Food rescue intervention evaluations: A systematic review. In <i>Sustainability (Switzerland)</i> (Vol. 11, Issue 23). MDPI.	Focuses on food system sustainability and waste reduction.	https://doi.org/10.3390/su11236718
10.	LEE, M., & GAMBIZA, J. (2022).	The adoption of conservation agriculture by smallholder farmers in southern Africa: A scoping review of barriers and enablers. In <i>Journal of Rural Studies</i> (Vol. 92, pp. 214–225). Elsevier Ltd.	Adoption and challenges of sustainable practices in smallholder farming.	https://doi.org/10.1016/j.jrurstud.2022.03.031
11.	MENSAH, H., AHADZIE, D. K., TAKYI, S. A., & AMPONSAH, O. (2021).	Climate change resilience: lessons from local climate-smart agricultural practices in Ghana. <i>Energy, Ecology and Environment</i> , 6(3), 271–284.	Localized practices for agricultural resilience in a changing climate.	https://doi.org/10.1007/s40974-020-00181-3
12.	MKUHLANI, S., ZINYENGERE, N., KUMI, N., & CRESPO, O. (2022).	Lessons from integrated seasonal forecast-crop modelling in Africa: A systematic review. In <i>Open Life Sciences</i> (Vol. 17, Issue 1, pp. 1398–1417). De Gruyter Open Ltd.	Use of forecasting and modeling for crop yield resilience.	https://doi.org/10.1515/biol-2022-0507

13.	MOLIELENG, L., FOURIE, P., & NWAFOR, I. (2021).	Adoption of climate-smart agriculture by communal livestock farmers in South Africa. In <i>Sustainability (Switzerland)</i> (Vol. 13, Issue 18). MDPI.	Evaluates sustainable farming techniques in livestock management.	https://doi.org/10.3390/su131810468
14.	MURKEN, L., & GORNOTT, C. (2022).	The importance of different land tenure systems for farmers' response to climate change: A systematic review. In <i>Climate Risk Management</i> (Vol. 35). Elsevier B.V.	Investigates tenure-related factors affecting climate resilience.	https://doi.org/10.1016/j.crm.2022.100419
15.	MWADZINGENI, L., MUGANDANI, R., & MAFONGOYA, P. (2022).	Risks of Climate Change on Future Water Supply in Smallholder Irrigation Schemes in Zimbabwe. In <i>Water (Switzerland)</i> (Vol. 14, Issue 11). MDPI.	Water security issues tied to climate change in small-scale farming.	https://doi.org/10.3390/w14111682
16.	NELSON, M., ZAK, K., DAVINE, T., & PAU, S. (2016).	Climate Change and Food Systems Research: Current Trends and Future Directions. <i>Geography Compass</i> , 10(10), 414–428.	Overview of climate change impacts on food systems.	https://doi.org/10.1111/gec3.12281
17.	PITTELKOW, C. M., LINQUIST, B. A., LUNDY, M. E., LIANG, X., VAN GROENIGEN, K. J., LEE, J., VAN GESTEL, N., SIX, J., VENTEREA, R. T., & VAN KESSEL, C. (2015).	When does no-till yield more? A global meta-analysis. <i>Field Crops Research</i> , 183, 156–168.	Analysis of no-till farming as a climate-resilient agricultural practice.	https://doi.org/10.1016/j.fcr.2015.07.020
18.	RATHGENS, J., GRÖSCHNER, S., & VON WEHRDEN, H. (2020).	Going beyond certificates: A systematic review of alternative trade arrangements in the global food sector. In <i>Journal of Cleaner Production</i> (Vol. 276). Elsevier Ltd.	Sustainable trade practices in global food production.	https://doi.org/10.1016/j.jclepro.2020.123208
19.	REZA, M. S., & SABAU, G. (2022).	Impact of climate change on crop production and food security in Newfoundland and Labrador, Canada. In <i>Journal of Agriculture and Food Research</i> (Vol. 10). Elsevier B.V.	Examines food security challenges from climate changes.	https://doi.org/10.1016/j.jafr.2022.100405
20.	ROMERO-PERDOMO, F., CARVAJALINO-UMAÑA, J. D., MORENO-GALLEGO, J. L., ARDILA,	Research Trends on Climate Change and Circular Economy from a Knowledge Mapping Perspective. <i>Sustainability (Switzerland)</i> , 14(1).	Investigates sustainable circular economy principles in the agro-sector	https://doi.org/10.3390/su14010521

	N., & GONZÁLEZ-CURBELO, M. Á. (2022).			
21.	RUWANZA, S., THONDHLANA, G., & FALAYI, M. (2022).	Research Progress and Conceptual Insights on Drought Impacts and Responses among Smallholder Farmers in South Africa: A Review. In <i>Land</i> (Vol. 11, Issue 2). MDPI.	Impact of drought on small-scale farming and adaptive responses.	https://doi.org/10.3390/land11020159
22.	SÁNCHEZ, A. C., KAMAU, H. N., GRAZIOLI, F., & JONES, S. K. (2022).	Financial profitability of diversified farming systems: A global meta-analysis. <i>Ecological Economics</i> , 201.	Financial viability of sustainable, diverse farming practices.	https://doi.org/10.1016/j.ecolecon.2022.107595
23.	SHAH, T. M., TASAWWAR, S., & OTTERPOHL, R. (2021).	Agroecology for food and water security in times of climate consciousness: A bibliometric analysis of peer-reviewed literature published from 1990 to 2020. <i>Sustainability (Switzerland)</i> , 13(9).	Agroecological practices as sustainable responses to climate.	https://doi.org/10.3390/su13095064
24.	VIGNOLA, R., ESQUIVEL, M. J., HARVEY, C., RAPIDEL, B., BAUTISTA-SOLIS, P., ALPIZAR, F., DONATTI, C., & AVELINO, J. (2022).	Ecosystem-Based Practices for Smallholders' Adaptation to Climate Extremes: Evidence of Benefits and Knowledge Gaps in Latin America. In <i>Agronomy</i> (Vol. 12, Issue 10). MDPI.	Sustainable ecosystem management in smallholder agriculture.	https://doi.org/10.3390/agronomy12102535
25.	ZAVALA-ALCÍVAR, A., VERDECHO, M. J., & ALFARO-SAIZ, J. J. (2020).	A conceptual framework to manage resilience and increase sustainability in the supply chain. In <i>Sustainability (Switzerland)</i> (Vol. 12, Issue 16). MDPI.	Resilience and sustainability in agricultural supply chains	https://doi.org/10.3390/SU12166300
26.	ZIA, B., RAFIQ, M., SAQIB, S. E., & ATIQ, M. (2022).	Agricultural Market Competitiveness in the Context of Climate Change: A Systematic Review. In <i>Sustainability (Switzerland)</i> (Vol. 14, Issue 7). MDPI.	Impact of climate on agricultural market dynamics.	https://doi.org/10.3390/su14073721

Table 5: Characteristics of studies included in the review from Google Scholar

	Author and Year	Title	Reason for inclusion	Link
1.	AFOKPE, P., PHIRI, A., LAMORE, A., TOURE, H., TRAORE, R., & KIPKOGEI, O. (2022).	Progress in climate change adaptation and mitigation actions in sub-Saharan Africa farming systems. <i>Cahiers Agricultures</i> , 31, 4.	Examines progress in climate adaptation and mitigation in sub-Saharan Africa's farming systems, assessing practices to improve resilience	https://doi.org/10.1051/cagri/2021037
2.	AHENKAN, A. (2019).	Financing climate change mitigation: an assessment of the private sector investment opportunities in Ghana. <i>Business Strategy & Development</i> , 3(1), 143-150.	Analyzes private sector investment opportunities in Ghana for climate change mitigation, highlighting financial strategies to address climate impact.	https://doi.org/10.1002/bsd2.84
3.	AKIL, L. & AHMAD, H. (2023).	Socioeconomic impacts of covid-19 pandemic on foodborne illnesses in the united states. <i>European Journal of Environment and Public Health</i> , 7(2), em0128.	Discusses the socioeconomic impact of COVID-19 on foodborne illnesses in the U.S., linking pandemic disruptions to public health.	https://doi.org/10.29333/ejeph/12585
4.	AMELEWORK, A., BAIRU, M., MAEMA, O., VENTER, S., & LAING, M. (2021).	Adoption and promotion of resilient crops for climate risk mitigation and import substitution: a case analysis of cassava for South African agriculture. <i>Frontiers in Sustainable Food Systems</i> , 5.	Looks at cassava as a resilient crop in South Africa to combat climate risks and reduce import dependency in agriculture.	https://doi.org/10.3389/fsufs.2021.617783

5.	AMOA, L. &AND SIMATELE, M. (2021).	Food security and coping strategies of rural household livelihoods to climate change in the eastern cape of South Africa. <i>Frontiers in Sustainable Food Systems</i> , 5.	Investigates rural household food security and coping mechanisms in the Eastern Cape of South Africa, focusing on climate resilience.	https://doi.org/10.3389/fsufs.2021.692185
6.	ANGULA, S., MOFOKENG, T., IKUMI, D., & BASITERE, M. (2022).	Potential co-disposal of food waste and sewage sludge in South Africa: a review.	Reviews co-disposal potential of food waste and sewage sludge in South Africa, assessing environmental and waste management practices.	https://doi.org/10.20944/preprints202208.0530.v1
7.	Arksey, H.; O'Malley, L (2005)	Scoping studies: Towards a methodological framework. <i>Int. J. Soc. Res. Methodol.</i> 2005, 8, 9–32.	This article presents a foundational framework for conducting scoping studies, offering key methodological insights that are essential for systematic reviews and literature mapping in social research fields, including food systems and climate change adaptation.	https://eprints.whiterose.ac.uk/1618/1/Scopingstudies.pdf Anderson
8.	ASSAN, N. (2022).	It's time for reimagining the future of food security in sub-Saharan Africa: gender-smallholder agriculture-	Explores food security challenges in sub-Saharan Africa, emphasizing the climate change,	https://doi.org/10.31586/ujfs.2022.504

		climate change nexus. Trends Journal of Sciences Research, 1(1), 76-85.	gender, and smallholder agriculture nexus.	
9.	ATWOLI, L., MUHIA, J., & MERALI, Z. (2022).	Mental health and climate change in Africa. Bjpsych International, 19(4), 86-89.	Analyzes the climate change impacts in Africa, focusing on psychological and social outcomes.	https://doi.org/10.1192/bji.2022.14
10.	Aung, M.M. & Chang, Y.S., 2014.	Traceability in a food supply chain: Safety and quality perspectives. Food Control, 39, pp.172-184.	Focuses on food supply chain traceability to ensure safety and quality, emphasizing agricultural impacts.	DOI: 10.1016/j.foodcont.2013.11.007.
11.	AVERBEKE, W. &AND KHOSA, T. (2018).	The contribution of smallholder agriculture to the nutrition of rural households in a semi-arid environment in South Africa. Water Sa, 33(3), 413.	Assesses smallholder agriculture's role in rural nutrition within semi-arid South Africa, highlighting climate challenges on food security.	https://doi.org/10.4314/wsa.v33i3.180612
12.	BANINLA, Y., SHARIFI, A., ALLAM, Z., PAUL, S., GANGTAR, N., & GEORGE, N. (2022).	An overview of climate change adaptation and mitigation research in Africa. Frontiers in Climate, 4.	Provides an overview of climate adaptation and mitigation research in Africa, evaluating current gaps and strategies.	https://doi.org/10.3389/fclim.2022.976427
13.	BERHANU, M. &AND WOLDE, A. (2019).	Review on climate change impacts and its adaptation strategies on food security in sub-Saharan Africa. Agricultural Social Economic Journal, 19(3), 145-154.	Reviews the impact of climate change on food security in sub-Saharan Africa and identifies adaptation strategies.	https://doi.org/10.21776/ub.agrise.2019.019.3.3

14.	BERTI, G. & MULLIGAN, C. (2016).	Competitiveness of small farms and innovative food supply chains: the role of food hubs in creating sustainable regional and local food systems. <i>Sustainability</i> , 8(7), 616.	Discusses small farms' competitiveness and the role of food hubs in building sustainable local food systems.	https://doi.org/10.3390/su8070616
15.	Bijani, M., Hayati, D., Azadi, H., Tanaskovik, V., & Witlox, F. (2020).	Causes and consequences of the conflict among agricultural water beneficiaries in Iran. <i>Sustainability</i> , 12(16), 6630	Examines conflicts among agricultural water beneficiaries in Iran, focusing on water scarcity and climate-driven disputes.	https://doi.org/10.3390/su12166630
16.	BLANC, E. (2012).	The impact of climate change on crop yields in sub-Saharan Africa. <i>American Journal of Climate Change</i> , 01(01), 1-13.	Investigates the potential effects of climate change on crop yields in sub-Saharan Africa, with an emphasis on food security risks.	https://doi.org/10.4236/ajcc.2012.11001
17.	BROWN, M., HINTERMANN, B., & HIGGINS, N. (2009).	Markets, climate change, and food security in west Africa. <i>Environmental Science & Technology</i> , 43(21), 8016-8020.	Looks at the impact of climate change on markets and food security in West Africa, evaluating trade and economic responses	https://doi.org/10.1021/es901162d
18.	CHAKWIZIRA, J. (2019).	Rural transport and climate change in South Africa: converting constraints into rural transport adaptation opportunities. <i>Jamba</i>	Examines how climate adaptation could be applied to rural areas in South Africa to improve productivity under climate constraints.	https://doi.org/10.4102/jamba.v11i3.718

		Journal of Disaster Risk Studies, 11(3).		
19.	CHALLINOR, A., WHEELER, T., GARFORTH, C., CRAUFURD, P., & KASSAM, A. (2007).	Assessing the vulnerability of food crop systems in Africa to climate change. Climatic Change, 83(3), 381-399.	Assesses the vulnerability of African food crop systems to climate change, identifying critical areas for adaptation.	https://doi.org/10.1007/s10584-007-9249-0
20.	CHERSICH, M. &AND WRIGHT, C. (2019).	Climate change adaptation in South Africa: a case study on the role of the health sector. Globalization and Health, 15(1).	Case study on the role of South Africa in climate adaptation, emphasizing public health resilience.	https://doi.org/10.1186/s12992-019-0466-x
21.	CONWAY, D., ARCHER, E., DERYNG, D., DORLING, S., KRUEGER, T., LANDMAN, W. & DALIN, C. (2015).	Climate and southern Africa's water-energy-food nexus. Nature Climate Change, 5(9), 837-846	Discusses Southern Africa's water-energy-food nexus under climate change, exploring interconnected resource impacts.	https://doi.org/10.1038/nclimate2735
22.	DANIELL, A. &AND TONDER, D. (2023).	Opportunity for increasing the soil quality of non-arable and depleted soils in South Africa: a review. Journal of Soil Science and Plant Nutrition, 23(2), 2476-2487.	Reviews ways to enhance soil quality on non-arable land in South Africa, focusing on sustainable agriculture practices.	https://doi.org/10.1007/s42729-023-01205-7
23.	DASAKLIS, T. &AND PAPPIS, C. (2013).	Supply chain management in view of climate change: an overview of possible impacts and the road ahead. Journal of	Overviews supply chain management challenges due to climate change, proposing strategies for resilience.	https://doi.org/10.3926/jiem.883

		Industrial Engineering and Management, 6(4).		
24.	DENNIS, I. &AND DENNIS, R. (2012).	Climate change vulnerability index for South African aquifers. Water Sa, 38(3).	Develops a climate vulnerability index for South African aquifers, addressing water resource management.	https://doi.org/10.4314/wsa.v38i3.7
25.	DUNJANA, N., DUBE, E., MOTSEPE, M., MADIKIZA, S., KGAKATSI, I., & NCHIZAH, A. (2022).	Sorghum as a household food and livelihood security crop under climate change in South Africa: a review. South African Journal of Science, 118(9/10).	Reviews sorghum's potential as a food security crop under climate change in South Africa, assessing its adaptability.	https://doi.org/10.17159/sajs.2022/13340
26.	FAROOQ, M., UZAIR, M., RAZA, A., HABIB, M., XU, Y., YOUSUF, M. & KHAN, M. (2022).	Uncovering the research gaps to alleviate the negative impacts of climate change on food security: a review. Frontiers in Plant Science, 13.	Identifies research gaps in addressing climate change's impacts on food security, suggesting avenues for future study.	https://doi.org/10.3389/fpls.2022.927535
27.	GBETIBOUO, G., RINGLER, C., & HASSAN, R. (2010).	Vulnerability of the South African farming sector to climate change and variability: an indicator approach. Natural Resources Forum, 34(3), 175-187.	Evaluates the vulnerability of South African farmers to climate variability, using indicators to assess resilience.	https://doi.org/10.1111/j.1477-8947.2010.01302.x
28.	GERKEN, A. &AND MORRISON, W. (2022).	Pest management in the postharvest agricultural supply chain under climate change. Frontiers in Agronomy, 4.	Explores pest management in agricultural supply chains under climate pressures, focusing	https://doi.org/10.3389/fagro.2022.918845

			on postharvest impacts.	
29.	GHADGE, A., WURTMANN, H., & SEURING, S. (2019).	Managing climate change risks in global supply chains: a review and research agenda. <i>International Journal of Production Research</i> , 58(1), 44-64.	Reviews climate risk management in global supply chains, proposing a research agenda to improve resilience.	https://doi.org/10.1080/00207543.2019.1629670
30.	GREGORY, P., INGRAM, J., & BRKLACICH, M. (2005).	Climate change and food security. <i>Philosophical Transactions of the Royal Society B Biological Sciences</i> , 360(1463), 2139-2148.	Discusses climate change's potential impacts on global food security, with a focus on agricultural production.	https://doi.org/10.1098/rstb.2005.1745
31.	GROTE, U., FAßE, A., NGUYEN, T., & ERENSTEIN, O. (2021).	Food security and the dynamics of wheat and maize value chains in Africa and Asia. <i>Frontiers in Sustainable Food Systems</i> , 4.	Examines wheat and maize value chains in Africa and Asia, focusing on food security and agricultural dynamics.	https://doi.org/10.3389/fsufs.2020.617009
32.	GUO, D., POWRIE, L., & BOYD, D. (2019).	Climate change and biodiversity threats on <i>Pachypodium</i> species in South Africa. <i>Journal of Geoscience and Environment Protection</i> , 07(05), 37-44.	Analyzes biodiversity threats due to climate change on <i>Pachypodium</i> species in South Africa.	https://doi.org/10.4236/gep.2019.75004
33.	GUO, X. (2023).	A vicious cycle between agriculture supply chain and climate change. Highlights in <i>Business Economics and Management</i> , 5, 317-323.	Describes the cycle between agriculture supply chains and climate change, examining feedback mechanisms.	https://doi.org/10.54097/hbem.v5i.5098

34.	HATAB, A. (2022).	Africa's food security under the shadow of the Russia-Ukraine conflict. Strategic Review for Southern Africa, 44(1).	Discusses the Russia-Ukraine conflict's effects on African food security, analyzing geopolitical and supply chain impacts.	https://doi.org/10.35293/srsa.v44i1.4083
35.	HEDLUND, J., CARLSEN, H., CROFT, S., WEST, C., BODIN, Ö., STOKELD, E. & MÜLLER, C. (2022).	Impacts of climate change on global food trade networks. Environmental Research Letters, 17(12), 124040.	Investigates climate change impacts on global food trade, analyzing vulnerabilities in supply networks.	https://doi.org/10.1088/1748-9326/aca68b
36.	HENDRIKS, S. & AND OLIVIER, N. (2015).	Review of the South African agricultural legislative framework: food security implications. Development Southern Africa, 32(5), 555-576.	Reviews South Africa's agricultural policies, evaluating their implications for food security.	https://doi.org/10.1080/0376835x.2015.1044075
37.	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC), 2021. Climate Change 2021:	The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.	The Sixth Assessment Report covers the physical science of climate change, highlighting impacts on ecosystems and human systems.	https://www.ipcc.ch/report/ar6/wg1/
38.	Ivanov, D., Dolgui, A., Sokolov, B., Ivanova, M. & Potryasaev, S., 2017.	Disruption-driven supply chain dynamics: A ripple effect modeling approach and case study. Transportation Research Part E: Logistics and	Examines supply chain disruptions due to climate-induced events, modeling the "ripple effect" in logistics.	DOI: 10.1016/j.tre.2016.05.020.

		Transportation Review, 90, pp.405-420.		
39.	KAPTYMER, B., UTE, J., & HULE, M. (2019).	Climate-smart agriculture and its implementation challenges in Africa. Current Journal of Applied Science and Technology, 1-13.	Discusses climate-smart agriculture and implementation challenges in Africa.	https://doi.org/10.9734/cjast/2019/v38i430371
40.	KAZEMBE, L., CRUSH, J., & WAGNER, J. (2020).	Revisiting the African supermarket revolution: the case of Windhoek, Namibia. Development Southern Africa, 38(2), 230-247	Reviews the African supermarket revolution, specifically in Namibia, and its implications for local food security.	https://doi.org/10.1080/0376835x.2020.1819774
41.	KHAN, M., AKRAM, M., JANKE, R., QADRI, R., AL-SADI, A., & FAROOQUE, A. (2020).	Urban horticulture for food secure cities through and beyond COVID-19. Sustainability, 12(22), 9592.	Highlights urban horticulture's role in food security, particularly during and beyond the COVID-19 pandemic.	https://doi.org/10.3390/su12229592
42.	KHEE, P., MEE, L., & KEONG, C. (2014).	The economic impact of climate change on food security in Malaysia. International Journal of Academic Research, 6(3), 195-199.	Analyzes climate change's economic impacts on Malaysia's food security, with a focus on policy recommendations.	https://doi.org/10.7813/2075-4124.2014/6-3/b.29
43.	KLAUSBRUCKNER, C., ANNEGARN, H., HENNEMAN, L., & RAFAJ, P. (2016).	A policy review of synergies and trade-offs in South African climate change mitigation and air pollution control strategies.	Reviews South Africa's climate mitigation and air pollution strategies, assessing synergies and trade-offs.	https://doi.org/10.1016/j.envsci.2015.12.001

		Environmental Science & Policy, 57, 70-78.		
44.	KURUKULASURIYA, P. & AND MENDELSON, R. (2008).	How will climate change shift agroecological zones and impact African agriculture?	Examines how climate change could shift African agroecological zones, impacting agriculture.	https://doi.org/10.1596/1813-9450-4717
45.	KWAME, A., DANNY, S., & REID, M. (2022).	The threats of climate change on water and food security in South Africa. American Journal of Environment and Climate, 1(2), 73-91.	Reviews climate threats to South Africa's water and food security, proposing resilience strategies.	https://doi.org/10.54536/ajec.v1i2.568
46.	LAKE, I. & AND BARKER, G. (2018).	Climate change, foodborne pathogens and illness in higher-income countries. Current Environmental Health Reports, 5(1), 187-196.	Discusses the impact of climate change on foodborne pathogens in high-income countries.	https://doi.org/10.1007/s40572-018-0189-9
47.	MACHATE, M. (2020).	The conundrums of the estimated magnitude of food waste generated in South Africa. International Journal of Sustainable Development and Planning, 15(6), 893-899.	Reviews estimates of food waste in South Africa, highlighting challenges in achieving sustainability.	https://doi.org/10.18280/ijmdp.150613
48.	MASIPA, T. (2017).	The impact of climate change on food security in South Africa: current realities and challenges ahead. Jambá Journal of Disaster Risk Studies, 9(1).	Assesses the impact of climate change on South Africa's food security, evaluating adaptation needs.	https://doi.org/10.4102/jamba.v9i1.411

49.	MENDELSON, R. (2009).	The impact of climate change on agriculture in developing countries. <i>Journal of Natural Resources Policy Research</i> , 1(1), 5-19.	Examines climate change impacts on agriculture in developing countries, identifying adaptation strategies.	https://doi.org/10.1080/19390450802495882
50.	MOHTAR, R. &AND FARES, A. (2022).	The future of water for food. <i>Frontiers in Sustainable Food Systems</i> , 6.	Looks at future water resource needs for global food production, emphasizing sustainable management.	https://doi.org/10.3389/fsufs.2022.880767
51.	MTHEMBU, A. &AND HLOPHE, S. (2021).	Building resilience to climate change in vulnerable communities: a case study of uMkhanyakude district municipality. <i>Town and Regional Planning</i> , 77.	Case study on building climate resilience in South Africa's uMkhanyakude district, focusing on community adaptation.	https://doi.org/10.18820/2415-0495/trp77i1.4
52.	MUGAMBIWA, S. &AND TIRIVANGASI, H. (2017).	Climate change: a threat towards achieving 'sustainable development goal number two' (end hunger, achieve food security and improved nutrition and promote sustainable agriculture) in South Africa. <i>Jamba Journal of Disaster Risk Studies</i> , 9(1).	Discusses climate change as a barrier to achieving Sustainable Development Goal 2 in South Africa.	https://doi.org/10.4102/jamba.v9i1.350
53.	MÜLLER, C., CRÄMER, W., HARE, B., & LOTZE-CAMPEN, H. (2011).	Climate change risks for African agriculture. <i>Proceedings of the</i>	Examines climate change risks for African agriculture,	https://doi.org/10.1073/pnas.1015078108

		National Academy of Sciences, 108(11), 4313-4315.	with a focus on vulnerability and resilience.	
54.	MUSANGO, J. &AND PETER, C. (2007).	A Bayesian approach towards facilitating climate change adaptation research on the South African agricultural sector. <i>Agrekon</i> , 46(2), 245-259.	Utilizes a Bayesian approach to study climate adaptation in South Africa's agriculture sector.	https://doi.org/10.1080/03031853.2007.9523770
55.	MUSVOTO, C., NORTJE, K., WET, B., MAHUMANI, B., & NAHMAN, A. (2015).	Imperatives for an agricultural green economy in South Africa. <i>South African Journal of Science</i> , 111(1/2), 1-8.	Outlines the requirements for a green economy in South Africa's agriculture sector, focusing on sustainability.	https://doi.org/10.17159/sajs.2015/20140026
56.	MYERS, S., SMITH, M., GUTH, S., GOLDEN, C., VAITLA, B., MUELLER, N. & HUYBERS, P. (2017).	Climate change and global food systems: potential impacts on food security and undernutrition. <i>Annual Review of Public Health</i> , 38(1), 259-277.	Reviews climate change impacts on food systems, assessing potential threats to food security and nutrition.	https://doi.org/10.1146/annurev-publhealth-031816-044356
57.	NCUBE, M., MADUBULA, N., NGWENYA, H., ZINYENGERE, N., ZHOU, L., FRANCIS, J., & MADZIVHANDILA, T. (2016).	Climate change, household vulnerability and smart agriculture: the case of two South African provinces. <i>Jambá Journal of Disaster Risk Studies</i> , 8(2).	Analyzes household vulnerability and smart agriculture strategies in South Africa's climate context.	https://doi.org/10.4102/jamba.v8i2.182
58.	Nhemachena, C. & Hassan, R., 2007.	Micro-level analysis of farmers' adaptation to climate change in	Studies farmer adaptation at the micro-level in	https://www.ifpri.org/publication/micro-level-analysis-farmers-adaptation-climate-change-southern-africa .

		Southern Africa. IFPRI Discussion Paper 00714, International Food Policy Research Institute (IFPRI).	Southern Africa, focusing on climate resilience.	
59.	ODIMEGWU, F. (2022).	Climate change and agriculture: analysis and implication on South Africa. African Social Science and Humanities Journal, 3(2), 1-19.	Reviews climate change's effects on South African agriculture, focusing on risks and adaptation.	https://doi.org/10.57040/asshj.v3i2.141
60.	ODUNIYI, O. &AND SYLVIA, T. (2019).	Establishing the nexus between climate change adaptation strategy and smallholder farmers' food security status in South Africa: a bi-casual effect using instrumental variable approach. Cogent Social Sciences, 5(1).	Investigates the link between climate adaptation and food security among South African smallholders.	https://doi.org/10.1080/23311886.2019.1656402
61.	OELOFSE, S. &AND NAHMAN, A. (2012).	Estimating the magnitude of food waste generated in South Africa. Waste Management & Research the Journal for a Sustainable Circular Economy, 31(1), 80-86.	Estimates the magnitude of food waste in South Africa, identifying critical areas for waste reduction.	https://doi.org/10.1177/0734242x12457117
62.	OELOFSE, S., MUSWEMA, A., & RAMUKHWATHO, F. (2018).	Household food waste disposal in South Africa: a case study of Johannesburg and Ekurhuleni. South African Journal of Science, 114(5/6), 6.	Examines food waste disposal practices in Johannesburg and Ekurhuleni, emphasizing waste management.	https://doi.org/10.17159/sajs.2018/20170284

63.	OLABANJI, M., NDARANA, T., & DAVIS, N. (2020).	Impact of climate change on crop production and potential adaptive measures in the Olifants catchment, South Africa. <i>Climate</i> , 9(1), 6.	This article examines the impacts of climate change on crop production in South Africa's Olifants catchment area and discusses adaptive measures to mitigate these effects. It focuses on agricultural resilience within the region.	https://doi.org/10.3390/cli9010006
64.	OLUOKO-ODINGO, A. &AND AYIEMBA, E. (2020).	Food security in the afro-china cooperation: the hanging, untapped 'win-win' partnership. <i>The African Review</i> , 47(2), 392-418.	This study explores Afro-Chinese cooperation, analyzing its potential for enhancing food security in Africa. The article emphasizes untapped opportunities in the partnership to benefit food systems through a "win-win" approach.	https://doi.org/10.1163/1821889x-12340025
65.	OMORUYI, O., DAKORA, E., & OLUWAGBEMI, O. (2022).	Insights into the impacts of and responses to the COVID-19 pandemic: The South African food retail supply chains perspective. <i>Journal of Transport and Supply Chain Management</i> , 16.	The focus here is on how South Africa's food retail supply chains responded to the COVID-19 pandemic. It provides insights into supply chain resilience and	https://doi.org/10.4102/jtscm.v16i0.739

			adaptability during the crisis.	
66.	OSEI, B., KUNAWOTOR, M., & APPIAH-KONADU, P. (2023).	Measures for achieving sustainable environment to mitigate climate change in Africa. <i>International Journal of Social Economics</i> , 51(4), 454-469.	This article reviews environmental measures in Africa aimed at achieving sustainability and reducing climate change impacts, highlighting policies and practices for ecological stability.	https://doi.org/10.1108/ijse-04-2023-0290
67.	PAGANINI, N., ADINATA, K., BUTHELEZI, N., HARRIS, D., LEMKE, S., ALBERTO, L. & STÖBER, S. (2020).	Growing and eating food during the COVID-19 pandemic: farmers' perspectives on local food system resilience to shocks in southern Africa and Indonesia. <i>Sustainability</i> , 12(20), 8556.	This work investigates food system resilience from the perspective of farmers in southern Africa and Indonesia during the COVID-19 pandemic. It looks at local food systems' capacity to withstand shocks.	https://doi.org/10.3390/su12208556
68.	PARFITT, J., BARTHEL, M., & MACNAUGHTON, S. (2010).	Food waste within food supply chains: quantification and potential for change to 2050. <i>Philosophical Transactions of the Royal Society B Biological Sciences</i> , 365(1554), 3065-3081.	This paper quantifies food waste within global food supply chains and projects potential reductions by 2050. It emphasizes the importance of reducing waste to improve food security.	https://doi.org/10.1098/rstb.2010.0126

69.	PARRY, M., ROSENZWEIG, C., & LIVERMORE, M. (2005).	Climate change, global food supply and risk of hunger. <i>Philosophical Transactions of the Royal Society B Biological Sciences</i> , 360(1463), 2125-2138.	This article assesses the risks climate change poses to global food supply, focusing on hunger and vulnerability. It provides models of how climate change could exacerbate food insecurity.	https://doi.org/10.1098/rstb.2005.1751
70.	PATRICK, H., KHALEMA, E., ABIOLU, O., IJATUYI, E., & ABIOLU, R. (2021).	South Africa's multiple vulnerabilities, food security and livelihood options in the COVID-19 new order: an annotation. <i>The Journal for Transdisciplinary Research in Southern Africa</i> , 17(1).	This study looks at food security vulnerabilities in South Africa during the COVID-19 pandemic. It addresses how the crisis has affected livelihood options and the country's food security landscape.	https://doi.org/10.4102/td.v17i1.1037
71.	PORTER, S., REAY, D., HIGGINS, P., & BOMBERG, E. (2016).	A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain. <i>The Science of the Total Environment</i> , 571, 721-729.	This article explores greenhouse gas emissions from food loss and waste in the production phase, highlighting the environmental costs and suggesting mitigation strategies.	https://doi.org/10.1016/j.scitotenv.2016.07.041
72.	RIBEIRO, P. & AND RODRIGUEZ, A. (2020).	Emerging advanced technologies to mitigate the impact of climate change in Africa. <i>Plants</i> , 9(3), 381.	This research focuses on emerging technologies that can mitigate climate change impacts in	https://doi.org/10.3390/plants9030381

			Africa. It discusses innovative approaches to enhancing climate resilience in agriculture.	
73.	RONQUEST-ROSS, L., VINK, N., & SIGGE, G. (2015).	Food consumption changes in South Africa since 1994. South African Journal of Science, 111(9/10), 12.	This paper reviews food consumption trends in South Africa since 1994, analyzing dietary shifts and their implications for nutrition and food security.	https://doi.org/10.17159/sajs.2015/20140354
74.	RURINDA, J., WIJK, M., MAPFUMO, P., DESCHEEMAEKER, K., SUPIT, I., & GILLER, K. (2015).	Climate change and maize yield in southern Africa: what can farm management do? Global Change Biology, 21(12), 4588-4601.	This study explores climate change effects on maize yields in southern Africa, proposing farm management techniques to mitigate these impacts and improve crop resilience.	https://doi.org/10.1111/gcb.13061
75.	SCHILLING, J., HERTIG, E., TRAMBLAY, Y., & SCHEFFRAN, J. (2020).	Climate change vulnerability, water resources and social implications in North Africa. Regional Environmental Change, 20(1).	This paper examines the vulnerability of water resources in North Africa due to climate change, discussing social and economic consequences for affected communities.	https://doi.org/10.1007/s10113-020-01597-7

76.	SCHMIDHUBER, J. &AND TUBIELLO, F. (2007).	Global food security under climate change. Proceedings of the National Academy of Sciences, 104(50), 19703-19708.	The article analyzes global food security in the context of climate change, examining how changing climates could affect food availability and access.	https://doi.org/10.1073/pnas.0701976104
77.	SEMENYA, K. (2023).	Comparative study of solid waste management in gaMothapo and Seshego in Polokwane local municipality Limpopo province, South Africa.	This study compares solid waste management in two South African municipalities, aiming to understand their environmental impacts and offer solutions for sustainable waste practices.	https://doi.org/10.21203/rs.3.rs-2451653/v1
78.	SHISANYA, S. &AND MAFONGOYA, P. (2017).	Assessing rural farmers perceptions and vulnerability to climate change in uMzinyathi district of KwaZulu-Natal, South Africa. African Journal of Agricultural Research, 12(10), 815-828.	This research investigates rural farmers' perceptions of climate change in KwaZulu-Natal, South Africa, and assesses their vulnerability and adaptive capacity.	https://doi.org/10.5897/ajar2016.11871
79.	SIMBA, S., NIEMANN, W., KOTZE, T., & AGIGI, A. (2017).	Supply chain risk management processes for resilience: a study of South African grocery manufacturers. Journal of Transport and Supply Chain Management, 11.	This paper examines risk management processes in South Africa's grocery supply chain, emphasizing resilience strategies	https://doi.org/10.4102/jtscm.v11i0.325

			to cope with supply chain disruptions.	
80.	SITHOLE, A. (2019).	Women's use of indigenous knowledge systems to cope with climate change. <i>Advances in Social Sciences Research Journal</i> , 6(6).	This article looks at how women in South Africa use indigenous knowledge to adapt to climate change, focusing on community-driven resilience strategies.	https://doi.org/10.14738/assrj.66.6470
81.	SUEBSOMBUT, P., SEKHARI, A., SUREEPONG, P., UEASANGKOMSATE, P., & BOURAS, A. (2017).	The using of bibliometric analysis to classify trends and future directions on "smart farm." 2nd Joint International Conference on Digital Arts, Media and Technology 2017: Digital Economy for Sustainable Growth, ICDAMT 2017, 136–141	This research uses bibliometric analysis to identify trends in smart farming, highlighting technology's role in sustainable agricultural growth.	https://doi.org/10.1109/ICDAMT.2017.7904950
82.	TERDOO, F. & AND FEOLA, G. (2016).	The vulnerability of rice value chains in sub-Saharan Africa: a review.	The focus is on the vulnerability of rice value chains in sub-Saharan Africa, with recommendations for strengthening resilience against climate threats.	https://doi.org/10.20944/preprints201608.0097.v1
83.	TERESSA, B. (2021).	Impact of climate change on food availability—a review. <i>International Journal of Food Science</i>	This review discusses climate change impacts on food availability, emphasizing the need	https://doi.org/10.26855/ijfsa.2021.09.017

		and Agriculture, 5(3), 465-470.	for strategies to protect food security under changing climate conditions.	
84.	THOW, A., GREENBERG, S., HARA, M., FRIEL, S., DUTOIT, A., & SANDERS, D. (2018).	Improving policy coherence for food security and nutrition in South Africa: a qualitative policy analysis. Food Security, 10(4), 1105-1130.	This article analyzes policy coherence in South Africa for enhancing food security and nutrition, recommending improvements to integrate food policy across sectors.	https://doi.org/10.1007/s12571-018-0813-4
85.	Tirado, M.C., Clarke, L., McMichael, A.J. & Dawe, D., 2013.	Climate change and food security: A framework document. Global Environmental Change, 23(4), pp.935-946.	This paper provides a framework for understanding the connections between climate change and food security, focusing on adaptation and resilience.	DOI: 10.1016/j.gloenvcha.2013.06.008.
86.	TIRIVANGASI, H. (2018).	Regional disaster risk management strategies for food security: probing southern African development community channels for influencing national policy. Jambá Journal of Disaster Risk Studies, 10(1).	The article reviews disaster risk management in southern Africa, emphasizing strategies for improving food security through regional policies.	https://doi.org/10.4102/jamba.v10i1.468
87.	TSHIKOVHI, M. &AND WYK, R. (2021).	South Africa's increasing climate variability and its effect on food production. Outlook on	This paper examines the effects of increasing climate variability on South	https://doi.org/10.1177/00307270211004970

		Agriculture, 50(3), 286-293.	African food production, discussing both challenges and adaptation strategies.	
88.	TUBIELLO, F., SOUSSANA, J., & HOWDEN, M. (2007).	Crop and pasture response to climate change. Proceedings of the National Academy of Sciences, 104(50), 19686-19690.	This study looks at how crops and pastures respond to climate change, analyzing adaptations necessary for sustained agricultural productivity.	https://doi.org/10.1073/pnas.0701728104
89.	TUMWESIGYE, W., ASCHALEW, A., WILBER, W., & DESTRA, A. (2019).	Impact of climate change on food systems: a narrative review. Journal of Water Resources and Ocean Science, 8(4), 50.	This review examines climate change impacts on food systems, providing an overview of vulnerabilities and potential resilience-building strategies.	https://doi.org/10.11648/j.wros.20190804.12
90.	UMAR, M. (2023).	Inherent and adaptive resilience of logistics operations in food supply chains. Journal of Business Logistics, 45(1).	The focus here is on resilience in logistics operations within food supply chains, with an emphasis on adaptability to climate and economic shocks.	https://doi.org/10.1111/jbl.12362
91.	UMETSU, C. & MIURA, K. (2023).	Building resilience for food and nutrition security in Africa: focusing on small-scale	This article examines food and nutrition security in Africa, particularly focusing	https://doi.org/10.7310/arfe.59.53

		farmers. <i>Journal of Rural Problems</i> , 59(1), 53-59.	on the resilience of small-scale farmers to climate-related challenges.	
92.	VERMEULEN, S., CAMPBELL, B., & INGRAM, J. (2012).	Climate change and food systems. <i>Annual Review of Environment and Resources</i> , 37(1), 195-222.	This paper provides an in-depth look at how climate change affects food systems globally, with strategies for adaptation and sustainability.	https://doi.org/10.1146/annurev-environ-020411-130608
93.	Wheeler, T. & von Braun, J., 2013.	Climate change impacts on global food security. <i>Science</i> , 341(6145), pp.508-513.	This article discusses the global impacts of climate change on food security, focusing on production, supply chains, and access to food.	DOI: 10.1126/science.1239402.
94.	WILLETT, C. (2021).	Food supply chain resilience in an era of climate change: recommendations for Toronto, Ontario.	The study focuses on food supply chain resilience in Toronto, recommending strategies for addressing climate change's impacts on food security.	https://doi.org/10.32920/ryerson.14654448.v1
95.	WYK, S. (2022).	Climate change law and policy in South Africa and Mauritius: adaptation and mitigation strategies in terms of the Paris	This article examines climate change law and policy in South Africa and Mauritius, discussing adaptation	https://doi.org/10.3366/ajicl.2022.0391

		Agreement. African Journal of International and Comparative Law, 30(1), 1-24.	and mitigation under the Paris Agreement.	
96.	ZIERVOGEL, G., NEW, M., ARCHER, E., MIDGLEY, G., TAYLOR, A., HAMANN, R. & WARBURTON, M. (2014).	Climate change impacts and adaptation in South Africa. Wiley Interdisciplinary Reviews Climate Change, 5(5), 605-620.	This article addresses climate change impacts and adaptation in South Africa, discussing how policies and practices can improve resilience.	https://doi.org/10.1002/wcc.295
97.	ZINYENGERE, N., CRESPO, O., & HACHIGONTA, S. (2013).	Crop response to climate change in southern Africa: a comprehensive review. Global and Planetary Change, 111, 118-126.	This comprehensive review explores how crops respond to climate change in southern Africa, proposing adaptation techniques to safeguard agriculture.	https://doi.org/10.1016/j.gloplacha.2013.08.010

Table 6: Reasons for exclusion of articles and number of articles excluded.

Reason for exclusion	Number of Articles
The study Focus did not align with the review focus.	2235
The outcome Variables did not align with the review.	3477
The Research Design did not align with the review.	1854
Discrepancies	2595
Subtotal	10161