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Assessing the Impact of Climate Change on Global Value Chain Participation: Evidence from Maize Farmers in the Eastern Cape, South Africa

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Abstract

Climate variability increasingly threatens smallholder agriculture in South Africa; however, limited attention has been given to its impact on integration into global value chains (GVCs). This study examined how climate variability influences smallholder maize farmers' participation in GVCs in the Eastern Cape province of South Africa. A mixed-methods approach was used, combining survey data from 200 farmers with qualitative interviews on perceptions and adaptation strategies. Ordered logistic regression results indicated that education ($\beta = 0.464$, $p = 0.023$), maize color ($\beta = 1.092$, $p = 0.005$), and income ($\beta = 0.220$, $p = 0.087$) significantly and positively affected participation. At the same time, rainfall variability and drought frequency had negative effects ($\beta = -0.621$, $p = 0.086$). These findings suggest that socioeconomic factors boost participation and resilience, whereas climate shocks and production uncertainty decrease competitiveness. Although existing training programmes increased awareness, their effect on market access remained limited. Farmers involved in GVCs showed greater capacity for adaptation compared to non-participants. Overall, climate shocks represent the chief obstacle to smallholder competitiveness, as socioeconomic resources provide only limited insulation against these risks. The study provides new evidence linking climate variability to GVC participation. It offers policy insights for promoting climate-smart agriculture, enhancing adaptive capacity, and encouraging inclusive market participation among smallholder farmers in South Africa.

Keywords: *Climate change, Global value chains, Maize farmers, Eastern Cape.*

1. Introduction

Climate change is widely recognised as one of the most urgent global challenges of the 21st century, with significant impacts on agricultural systems and food security, especially in developing countries like South Africa. According to the Intergovernmental Panel on Climate Change (IPCC), climate-related disruptions such as rising temperatures, changing rainfall patterns, and more frequent extreme weather events are already harming food production and access in vulnerable regions (IPCC, 2022). In South Africa, shifts in temperature, altered rainfall patterns, and an increase in extreme weather are affecting food production and disproportionately impacting small-scale and subsistence farmers (Nhliziyo & Mushunje, 2024). These farmers are essential to local food systems, yet they are often the most vulnerable to climate-related shocks (Harvey et al., 2018). Most small-scale farmers in rural South Africa rely on rain-fed agriculture, leaving them highly vulnerable to weather disruptions that directly reduce crop yields, farm income, and long-term sustainability (Rankoana, 2022).

As the leading maize producer in Africa, South Africa plays a vital role in ensuring regional food security and bolstering its agricultural economy. Maize is the country's most important crop, contributing approximately R9.5 billion annually to the national economy (Mangani et al., 2025). South Africa ranks ninth globally and second in sub-Saharan Africa for maize production (DAFF, 2016), underscoring its strategic significance in both regional and international markets. In the Southern African Development Community (SADC), South Africa remains one of the largest and most efficient maize producers (Matimolane et al., 2022). Maize farming accounts for about 60% of the country's total arable land and nearly 70% of its grain output (Glauber and Anderson, 2025). During the 2021/2022 season, South Africa produced around 15 million metric tonnes of maize, a slight decrease from 16.3 million tonnes the previous season but still well above the 10-year average harvest of 12.8 million tonnes (Adama, 2023). Three provinces produce the majority of this total (around 63%): the Free State leads with 39%, followed by the North West at 23%, and Mpumalanga at 21% (Mangani, 2025). These figures highlight South Africa's dominant role in the regional maize supply chain and its ongoing contribution to both domestic food security and export markets.

Disruptions in South Africa's maize production due to climate variability have wider implications for regional and global food markets (Affoh et al., 2022). South Africa, as Africa's top maize producer, plays a crucial role in ensuring regional food security and contributing to global grain markets (IFPRI, 2024). Maize is a staple food for millions and is vital for livestock feed, making its consistent production essential. However, climate variability, including unpredictable rainfall, rising temperatures, and prolonged droughts, increasingly threatens the country's maize output. Since about 80% of South Africa's maize is grown under rain-fed conditions, it remains highly vulnerable to these environmental changes (Matandirotya et al., 2022). This vulnerability has caused significant yield reductions during adverse weather, with ripple effects across Southern Africa. When South Africa experiences poor harvests, regional food prices tend to increase, and countries relying on imports may face supply shortages (Tesfamariam et al., 2022). Additionally, global markets can also be impacted, particularly in years when South Africa exports maize to countries like Japan, South Korea, and Zimbabwe (DAFF, 2021). While extensive literature exists on the relationship between climate change and agricultural productivity, much of the current research focuses on production output and food availability. Limited attention has been given to the structural barriers that climate change creates for small-scale farmers' integration into markets and global value chains. The link between climate change effects at the farm level and smallholder farmers' participation in global value chains remains largely unexplored. This gap is significant because maize is not only a staple food crop in South Africa but also a major traded commodity.

This paper addresses a key research gap by examining how climate change affects the participation of small-scale maize farmers in global food value chains. The study aims to analyse farm-level challenges among smallholder maize producers and determine how these issues affect their competitiveness in international markets. Unlike research that only concentrates on productivity or environmental sustainability, this paper adopts a comprehensive approach by connecting climate vulnerability with involvement in value chains. In doing so, it offers insights into the barriers faced and the opportunities available for smallholder farmers to adapt to climate change. Ultimately, the study aims to inform strategies for climate mitigation and, most importantly, promote the inclusion and participation of small-scale farmers in global food value chains.

2. Literature Review

Participation in global value chains (GVCs) is an ongoing process that has been thoroughly examined in both empirical and theoretical literature. The concept appears in recent empirical studies and traces back to earlier theoretical frameworks, such as GVC theory and dependency theories. This section, therefore, aims to analyse both the theoretical foundations and the empirical evidence related to participation in global value chains.

2.1 Theoretical Literature

2.1.1 Dependency Theory

The dependency theory developed in the 1940s and 1950s through the work of Raúl Prebisch and Hans Singer, offering a structuralist critique of global trade and development patterns. The Prebisch-Singer thesis suggests that peripheral economies, which heavily depend on exporting raw materials and primary commodities, face long-term declines in their terms of trade compared to industrialised core economies (Prebisch, 1987). This perspective was expanded in the 1960s and 1970s by scholars such as Paul Baran, Andre Gunder Frank, and Fernando Henrique Cardoso, who argued that underdevelopment results not from internal inefficiencies but from the systemic reproduction of structural inequalities within the global economic system (Chew & Lauderdale, 2010). Rather than attributing the exclusion of smallholder farmers to their limited size, dependency theory asserts that structural and historical inequalities within the global economic system drive their marginalisation. This sets the stage for the next theoretical perspective, Global Value Chain theory, which examines how participation can still be fostered within these global systems.

2.2.2 The Global Value Chain (GVC) Theory

The GVC theory builds on these structural concerns from dependency theory. However, it shifts the focus toward understanding how firms, producers, and suppliers are integrated into or excluded from global production and trade networks. Developed by Gereffi, Humphrey, and Sturgeon (2005), the GVC framework examines how value is created, governed, and captured at various stages along global supply chains. It identifies five governance structures: market, modular, relational, captive, and hierarchical, which are based on transaction complexity, the ability to codify information, and supplier capabilities. This framework is especially helpful for analyzing small-scale farmers' participation in global value chains, as it outlines the specific requirements and institutional arrangements that enable or hinder entry and upgrading within these systems. While GVC theory offers a practical lens for identifying entry points and governance structures, it does not negate the structural inequalities highlighted by dependency theory. Instead, it complements them by showing how participation can occur within global markets despite persistent barriers. With these theoretical foundations in place, the next section presents empirical findings on the factors influencing smallholder participation in global value chains, drawing on evidence from various contexts.

2.3 Empirical Literature

Climate change has significantly disrupted global value chains (GVCs), affecting production, trade, and participation across various economies. By damaging agricultural productivity and destroying critical infrastructure, extreme weather events such as droughts and floods severely hinder market integration at a global level. Wonyra and Gnedeka (2022) emphasise that in developing economies, where agriculture is the main sector and adaptive capacity is low, climate shocks reduce competitiveness and limit GVC involvement. The extent of these impacts varies based on a country's level of development and structural capacity. Teş and Şanlısoy (2025) found that although GVC participation improves trade performance, the benefits depend on institutional readiness and resilience. Similarly, Guo et al. (2024) indicate that droughts significantly decrease export value-added in Chinese manufacturing, underscoring the need for climate-resilient production systems.

Smallholder farmers are disproportionately affected in the agricultural sector. Thompson et al. (2023) demonstrate that extreme events, such as hurricanes, destroy smallholders' production and market access, creating a "double exposure" to environmental and economic risks. Recent policy developments, such as the 2023 Emirates Declaration on Sustainable

Agriculture at COP28, recognise the urgent need to make agrifood systems more resilient. However, Swinnen et al. (2022) observe that structural fragmentation in agricultural systems limits the adoption of climate-smart practices by smallholders, underlining the need for supportive value chains. Structural constraints, including weak infrastructure, limited financing, and land fragmentation, continue to hinder smallholder participation in agricultural value chains. Broader research examines how GVCs influence climate risks. Ates and Sanlisoy (2024), along with Naicker et al. (2025), show that GVC activities can increase environmental pressures through emissions and resource use, particularly in developing countries with limited ecological oversight. This link between climate change and GVCs underscores the importance of trade policies that prioritise sustainability.

Theoretically, GVC and dependency theories used in this study suggest that value creation and upgrading rely on technological capacity and strong connections within the chain. Dependency theory, on the other hand, emphasizes the structural inequalities that keep developing countries dependent on developed nations for technology and market access. Together, these frameworks explain why smallholders in developing economies often remain on the margins of GVCs, especially as climate conditions worsen. The Eastern Cape province of South Africa mirrors these broader global patterns. The region's smallholder maize farmers face repeated droughts, limited market access, and infrastructural gaps, all of which hinder their ability to join and benefit from global value chains. Understanding how climate change interacts with these structural and institutional challenges is crucial for creating inclusive, climate-resilient agricultural value chains.

3. Research Methodology

3.1 Research Design

This study employs a mixed-methods approach that integrates quantitative and qualitative data to examine how climate change affects smallholder maize farmers' participation in global value chains in South Africa. As noted by Molina-Azorín (2018), combining these methods allows the strengths of each to complement the other, producing a more comprehensive analysis. Similarly, Almeida (2018) argues that integrating quantitative and qualitative approaches within a single study provides a broader and more complete understanding of complex research problems.

In this study, the quantitative component focuses on yields, income, and market access to assess the effects of climate variability on competitiveness, while the qualitative component uses interviews with farmers to explore perceptions, adaptation strategies, and local challenges. This integrated design captures both measurable impacts and lived experiences, offering a holistic understanding of how climate change shapes smallholder participation and resilience in global markets.

3.2 Study Area

The study was conducted in the Eastern Cape province of South Africa, a region characterised by smallholder maize farmers who struggle with low yields and weak market integration despite targeted agricultural assistance (Lesala & Obi 2023). With a mostly rural population, the province continues to struggle with poverty, unemployment, and poor market access (Shava, 2024). Data was collected in the Joe Gqabi, Alfred Nzo, Amathole, Chris Hani, and OR Tambo districts to assess how climate change impacts maize production and farmers' participation in global value chains. Figure 1 shows the study area with the dark highlighted part showing the selected district municipalities.

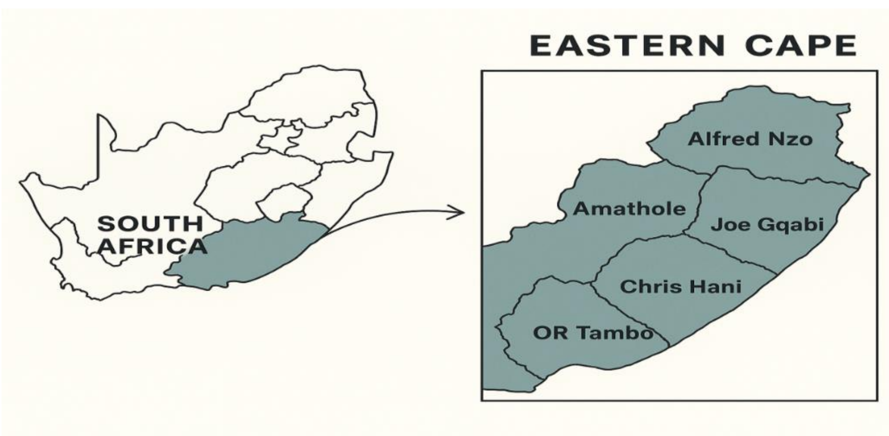

Figure 1: *Study area, source: authors' computation*

3.3 Target Population and Sampling Techniques

A representative sample was essential for studying smallholder maize farmers' participation in global value chains in the Eastern Cape. A multistage sampling method was used, which suits large and spread-out populations (Arrogante, 2024). The study purposely selected districts characterised by higher maize yields and climate risks, subsequently randomly sampling active farmer groups within those areas. Sampling frames created in partnership with local agricultural offices ensured diversity in farmer demographics, farm sizes, and programme participation. Combining purposive and random sampling improved the sample's representativeness and aligned with the study's goals.

3.3.1 Sample Size Determination

The sample size was determined using a statistical formula with finite population correction, which is suitable when the total population is known. Records from agricultural offices indicated that there are 12,689 registered smallholder maize farmers. A pilot study revealed that 84.4% of respondents exhibited traits, including climate awareness and active market participation. This approach is commonly employed in agricultural research, as seen in the work of Munzhelele et al. (2016). Using Neyman's (1934) and Cochran's (1977) adjusted formula,

$$n = \frac{Z^2 \times p \times (1-p)}{e^2} \times \frac{N}{N + (\frac{Z^2 \times p \times (1-p)}{e^2} - 1)}$$

Where: - n = required sample size, - N = population size (12,689 in this case), - Z = Z-score corresponding to the confidence level (1.96 for 95%), - p = estimated population proportion (0.844), - e = margin of error (0.05 or 5%). Using this method guarantees a statistically justified sample size of 200, offering reliable results with a 95% confidence level and ±5% margin of error. (Cochran, 1977). Basing the calculation on pilot-derived proportion data improves the representativeness and efficiency of the sample.

3.4 Data Collection

The study used a mixed-methods approach to investigate the impact of climate change on global value chain participation among smallholder maize farmers in the Eastern Cape. Structured questionnaires gathered data on yields, input costs, market access, climate variability, and adaptation strategies. Local fieldworkers conducted culturally sensitive interviews, with input from extension officers and farmer representatives, to improve the process. Quantitative data were analysed with Stata, while qualitative data were reviewed thematically, providing detailed insights into climate-related barriers and farmers' responses.

3.5 Analytic Framework

Logistic regression is a widely applied method for binary outcomes, making it suitable for estimating the likelihood of smallholder participation in global value chains based on various independent variables (Gujarati & Porter, 2009; Hosmer, Mark, et al., 2025; Sah & Devkota, 2024). In this study, an ordinal logistic regression was employed to analyse farmers' perceptions of climate change impacts on maize yields, measured through survey responses ranging from "no change" to "significant decrease." Since the response categories are ordinal but not equally spaced, this method is appropriate. Similar approaches have been used to evaluate farmers' interpretations of climate effects on productivity and market access (Nkondze, Masuku & Manyatsi, 2013). Furthermore, logistic models enable researchers to examine simultaneously the various socioeconomic, institutional, and agronomic factors that influence smallholders' integration into global markets (Elkahwagy et al., 2024). The model was specified as follows. Let Y_i represent the binary outcome indicating whether the farmer participated in the global value chain (Y_i = 1) or not (Y_i = 0). The logit model is defined as:

$$\text{logit}(P_i) = \ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} + \varepsilon_i$$

Where:
- P_i is the probability that $Y_i = 1$
- $X_1, X_2, \ldots, X_k$ are the explanatory variables
- β_0 is the intercept and $\beta_1 \ldots \beta_k$ are the coefficients to be estimated
- ε_i is the error term (Gujarati & *Porter*, 2009).

As previously explained, climate change is a key explanatory variable, with participation as the primary dependent variable. Table 1 provides a detailed overview of all other explanatory variables used in the regression analysis, including climate change. The table further details the anticipated effects of the selected variables, illustrating how they are expected to influence participation rates.

Table 4: Description of variables used in the model

Variable	**Type**	**Measurement Scale**	**Description**	**Expected Sign**	**Explanation**
Climate impact (production) *Rainfall variability* *Drought Frequency* *Change of season* *Pest and diseases*	Categorical	Categorical	Whether the farmer reported being affected by each climate change variable	±	May depend, both participating and non-participating may be affected or not affected
Climate effect on participation	Binary	Categorical	Whether the effect of climate affected the farmer on participation	±	May depend, both participating and non-participating may be affected or not affected
Age	Ordinal	Numeric or brackets	Age of the farmer	±	
Gender	Categorical	0 = Female, 1 = Male	Farmer's gender	+	May depend on gendered access to resources
Education	Ordinal	1 = No school to 6 = Postgrad	Education level	±	Improves risk perception and adaptive capacity
Income	Continuous	Local currency	Estimated monthly/annual income	+	Improves knowledge sharing and input access
Farming system	Categorical	Mixed, mono-crop, etc.	Type of production system	+	Reduces vulnerability to climate effects
Adaptation strategies	Categorical	Count or index	Type or quality of adaptive strategies used	+	Improve production and participation

Adopted changes	Categorical	Count or index	Type of adopted changes	+	Improve effectiveness of climate change adaptability

3.6 Ethical Considerations

This study adhered to ethical standards for research involving human subjects. Ethical approval was secured from the Cape Peninsula University of Technology Research Ethics Committee, referenced as 231238584/08/2024. Participation was voluntary, and all participants gave informed consent. The data were anonymised to protect their identities.

3.7 Acknowledgements

The authors wish to thank the smallholder farmers in the Eastern Cape across the five district municipalities for their generous sharing of time and experiences during the survey and interviews. We also acknowledge the support of local agricultural extension officers from the Eastern Cape, who, as part of the Department of Rural Development and Agrarian Reform (DRDAR), helped with farmer access and data collection.

3.8 Author Contributions

- **Aneza Madini**: Conceptualization, data collection, formal analysis, and original draft writing.
- **Thembalethu Seti**: Methodology, supervision, validation, writing, viewing, and editing.

3.9 Funding

This work was partly funded by the National Research Foundation (NRF).

3.10 Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

3.11 Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Cape Peninsula University of Technology or any affiliated institutions.

4. Findings and Discussion

This section presents and discusses the empirical findings regarding the impact of climate change smallholder maize farmers' participation in global value chains (GVCs) in South Africa's Eastern Cape province. The results combine both quantitative and qualitative data to provide a comprehensive view of farmers' socioeconomic conditions, climate-related challenges, and GVC participation patterns.

4.1 Overview and Participant Characteristics

The analysis starts with an overview of the demographic and farm-related characteristics of the respondents, which helps contextualise their ability to adapt to climate variability. It summarises key variables, including age, gender, education level, farm size, income, and cooperative membership, providing insight into the makeup of the study sample.

4.1.1 Age Distribution

The study surveyed smallholder maize farmers in the Eastern Cape to understand their involvement in global value chains (GVCs) and how climate variability affects them. The age distribution shows that most farmers are middle-aged or older, reflecting broader trends in rural South Africa (Heide-Ottosen, 2014), as illustrated in Figure 2 below.

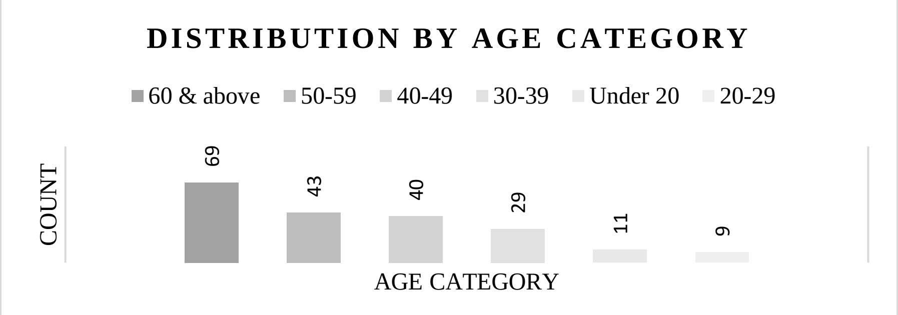

Figure 2: *Age categories. Source: Author's computation*

As shown in Figure 2 above, the low involvement of youth raises concerns about the long-term sustainability, competitiveness, and adaptability of the agricultural sector. Younger farmers are generally more willing to try new technologies, climate-smart practices, and market innovations that boost productivity and resilience. In contrast, the dominance of older farmers, who may be less willing or able to adopt innovative methods, poses a risk to the sector's ability to respond effectively to climate change and shifting market demands (Brown et al., 2019). This generational gap compromises the preservation of traditional agricultural knowledge and slows down the uptake of digital tools and sustainable practices required to modernise farming systems.

4.1.2 Participant Characteristics and Climate Change Impacts on Participation

Socioeconomic factors strongly influence participation. Income, education, and marital status are key contributors. Table 2 below shows results from participants on how gender, income, marital status, and education affect farmers' participation.

Table 2: Participant Overview and Participation Analysis

Variable	**Category**	**Participating**	**Not Participating**
Gender	Male	45	74
	Female	32	49
Income	R500 – R10,000	72	59
	R100,000 and above	44	11
Marital Status	Married	63	29
	Unmarried	61	47
Education	No formal education	14	24
	Primary to Secondary	124	76
Tertiary Education	—	0	0
Export Licenses	—	0	0

Table 2 above shows that farmers with higher incomes and those who completed primary to secondary education are more likely to participate, while marital support appears to increase involvement. Gender differences are small, indicating that both men and women are engaged in maize production, although slightly fewer women participate in GVCs. Education gaps remain, as many farmers lack tertiary qualifications; this suggests that while formal higher education is not a strict requirement for participation, it could significantly enhance innovation and adaptability. Climate issues like rainfall variability, drought, pests, and changing seasons affect all farmers. However, those in GVCs and with some education are better able to adapt. These trends highlight the connection between socioeconomic resources, knowledge, and climate resilience in shaping farmers' participation in global markets.

4.1.3 Effects of Climate Change on Participation in GVCs

Farmers encounter various climate-related challenges, such as rainfall variability, droughts, shifting seasons, and pest outbreaks. These disruptions harm production, lower incomes, and limit access to formal markets. Nonetheless, those engaged in GVCs generally have a greater ability to adapt compared to non-participants.

Table 3: Effects of Climate Change on Smallholder Farmers

Group	Climate Change Effect	Number of Farmers	% within Group
Not Participating (75)	Rainfall/Drought	50	66.7%
	Change of Season	12	16.0%
	Pests & Diseases	13	17.3%
Participating (122)	Rainfall/Drought	74	60.7%
	Change of Season	22	18.0%
	Pests & Diseases	26	21.3%
Total Farmers Affected (197)	—	200	100%
Adapted to Changes (Participating Only)	—	122	100%
Educated Farmers (Adopters)	—	122	100%
From those who adopted changes	Saw changes effective	73	—
Educated (Primary to Secondary)	—	54	—
Farmers not participating	Climate change limits competitiveness	5	—
Not Participating (Extra)	—	13	—

As shown in Table 3, 66.7% of farmers who did not participate cited rainfall and drought as their main concerns, compared to 60.7% of participants. A higher proportion of GVC participants noted shifts in seasons and rising pest or disease pressures, demonstrating a clearer recognition of climate risks and a greater tendency to implement adaptive measures. Remarkably, all participating farmers reported using some climate response strategies, with 73 confirming their effectiveness. In contrast, non-participants showed limited adaptive capability, with some saying that climate change has made it harder to compete.

These patterns indicate that participating in the value chain and gaining education strengthen climate resilience. This analysis prepares the way for a more detailed examination using an ordered logistic regression model in the next section.

4.2 Regression Analysis: Ordered Logistic Model

To assess the impact of climate change on the participation of smallholder maize farmers in global value chains, an ordered logistic regression model was employed. An ordinal regression model is suitable here because the dependent variable captures sequential levels of participation, representing different degrees of involvement instead of a simple binary choice. Table 4 below displays the results of the regression analysis with the ordered logistic model.

Table 4: Ordered Logistic Regression Model Analysis

Variables	Coefficient	Std. Err.	z	P>|z|	[95% Conf. Interval]
Socioeconomic Variables					
Gender	-0.2097	0.3719	-0.56	0.573	-0.9388 – 0.5194
Age	0.1165	0.1320	0.88	0.378	-0.1423 – 0.3753
Marital Status	-0.3655	0.1986	-1.84	0.066*	-0.7548 – 0.0238
Education	0.4644	0.2050	2.27	0.023**	0.0626 – 0.8662
Climate Variables					
Climate Effects (Participation) Rainfall/Drought frequency	-0.6211	0.3622	-1.71	0.086*	-1.3310 – 0.0888
Climate Effects (Direct production of maize)	-0.0472	0.2218	-0.21	0.831	-0.4820 – 0.3876
Impact on production	-0.1128	0.2503	-0.45	0.652	-0.6034 – 0.3778

Farm Costs	-1.1559	0.7029	-1.64	0.100	-2.5338 – 0.2220
Increased Production Costs	0.1883	0.2399	0.78	0.433	-0.2820 – 0.6586
Adaptation Changes	0.2913	0.3530	0.83	0.409	-0.4007 – 0.9833
Methods Used	-0.1621	0.1779	-0.91	0.362	-0.5109 – 0.1867
Competitiveness	0.1833	0.1844	0.99	0.320	-0.1782 – 0.5448
Competition (Global)	-0.2396	0.1804	-1.33	0.184	-0.5934 – 0.1142
Income	0.2198	0.1283	1.71	0.087*	-0.0318 – 0.4714
Funding Source	-0.3327	0.2205	-1.51	0.131	-0.7648 – 0.0994
Employment Status	0.0858	0.1451	0.59	0.554	-0.1986 – 0.3702
Seed Variety	-0.1695	0.2257	-0.75	0.453	-0.6118 – 0.2728
Maize Colour	1.0919	0.3853	2.83	0.005**	0.3368 – 1.8470
Farming System	0.7120	0.9282	0.77	0.443	-1.1072 – 2.5312
Training Services	-0.4812	0.4663	-1.03	0.302	-1.3951 – 0.4327
Formal Training (Exports)	-2.0711	0.8942	-2.32	0.021**	-3.8237 – -0.3185
Thresholds					
/cut1	-7.3135	2.5780			-12.3663 – -2.2606
/cut2	-2.5123	2.4493			-7.3130 – 2.2883

Notes: p-values in parentheses. ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively; $p < 0.05$ indicates significance, while $p > 0.05$ indicates non-significance

Results on Table 3 above indicate that education has a positive and significant effect on participation at the 5% level ($p = 0.023$), indicating that farmers with higher education levels are more likely to engage in GVCs, as education improves access to information, adoption of modern techniques, and compliance with international quality standards (Raji et al., 2020). Maize color also significantly predicts participation, reflecting industry and consumer preferences that impact market integration (De Groote, 2012). Maize colour has the strongest and most significant effect at the 1% level (p = 0.005), highlighting its critical role in influencing market dynamics. Farmers identified maize color as a key factor in their production decisions, with yellow maize favored by those who also raise livestock due to its dual use as food and feed. This suggests that colour preferences are not just aesthetic but functional and market-oriented, affecting both household subsistence and commercial strategies.

Income has a positive, though modest, effect on participation, significant at the 10% level (p = 0.087), suggesting that farmers with higher incomes are better able to manage production risks and invest in meeting market demands. Climate factors, remarkably rainfall variability and drought frequency, negatively affect participation, with a significant effect at the 10% level (p = 0.086), indicating that environmental shocks reduce production, increase uncertainty, and diminish smallholders' reliability as suppliers (Abebaw et al., 2025). Interestingly, formal training programmes exhibited a negative correlation with market participation, suggesting that certain initiatives may be poorly targeted, poorly adapted to local conditions, or inadvertently increase awareness of compliance costs, thereby discouraging involvement. Variables such as gender, farm costs, adaptation strategies, and farming systems were not found to be significant. These findings align with the descriptive results and emphasize that structural and climate factors are the main determinants of participation (Table 4).

4.3 Climate Impacts and Adaptation

In an era of increasing environmental uncertainty, changing socioeconomic conditions, and volatile markets, smallholders face a complex array of pressures, from population growth and land degradation to climate change and political instability (Touch et al., 2024). These challenges are worsened by unpredictable rainfall, droughts, and pest outbreaks, which reduce surplus production and limit access to formal markets (Waqas et al., 2025). Although educated farmers linked to global value chains adopt adaptive strategies that enhance resilience, many others are constrained by a lack of training and financial support. This gap highlights the urgent need for locally rooted, inclusive interventions that encourage broader participation and long-term adaptation. In an era of rising environmental uncertainty, shifting socioeconomic conditions, and unstable markets, smallholders face a complex range of pressures, from population growth and land degradation to climate change and political unrest (Touch et al., 2024). These challenges are intensified by unpredictable rainfall, droughts, and pest outbreaks, which decrease surplus production and restrict access to formal markets (Waqas et al., 2025). While farmers with education and ties to global value chains tend to adopt adaptive strategies that boost resilience, many others are hampered by a lack of training and financial backing. This gap underscores the urgent need for locally rooted, inclusive strategies that promote broader participation and long-term adaptation.

4.4 Implications and Discussion

The findings have important implications for policy and practical use. Education and information access are key to increasing smallholder participation. Machimu (2023) argues that cooperative education and agricultural information are vital for enabling smallholders to contribute to global solutions for agricultural challenges. Improving extension services, training, and educational programs can help farmers adopt new techniques and meet market standards. This is backed by Anderson and Feder (2004), who observe that changes in agriculture, new technologies, limited public budgets, decentralisation efforts, and emerging information and communication technologies (ICT) have created various, often more affordable, extension and advisory services that rely on both public and private funding and delivery methods. These findings highlight the lively interaction between dependency structures and GVC governance under climate stress conditions. From a dependency point of view, smallholders in peripheral economies remain structurally limited by restricted access to finance, technology, and market information, reinforcing unfair trade relations with dominant global players. However, the GVC framework indicates that even amid these imbalances, chances for functional upgrading and relational governance can emerge when farmers are supported through inclusive partnerships and adaptable institutional arrangements. Thus climate shocks expose production vulnerabilities and reveal governance gaps in value chains, emphasising the need for climate-resilient governance models that balance local capacity with global market requirements.

The importance of maize color highlights the need to align production with market demand, indicating that crop selection and diversification should consider local conditions and consumer preferences. Climate risks like drought and irregular rainfall continue to restrict participation, emphasising the need for targeted adaptation methods, including drought-tolerant varieties, irrigation support, and risk-sharing mechanisms. These findings are similar to those of Chami and Moujabber (2022), who outlined a roadmap with: (1) crop research to develop drought- and heat-tolerant varieties; (2) more research into farming practices; (3) better water use in agriculture; and (4) incorporating these goals into a sustainable research framework.

The unexpected negative effect of formal training indicates that capacity-building efforts should be relevant, inclusive, and responsive to smallholders' needs. The positive impact of income underlines the presence of financial barriers, suggesting that better access to credit or subsidies could effectively enhance market participation. Overall, these results suggest that integrating smallholders into global value chains requires a coordinated approach that includes education, climate adaptation, crop choices, and financial aid. Customised structural policies and interventions can strengthen their resilience, competitiveness, and sustainability amid environmental and market uncertainties.

5. Conclusions and Recommendations

This study investigated the impact of climate variability on the participation of smallholder maize farmers in global value chains in South Africa's Eastern Cape. It found that fluctuations in rainfall, extended droughts, and pest outbreaks significantly hinder farmers' competitiveness. Slight improvements in adaptive capacity were linked to education and income levels. Farmers engaged in global value chains showed greater resilience and adopted more adaptive strategies than those outside these chains, highlighting the importance of market access in climate adaptation. However, training and institutional support only partially met local needs, revealing existing gaps. Notably, maize colour was identified as the most statistically significant factor influencing participation, with yellow maize being particularly valued by farmers who also keep livestock. This indicates that production and marketing choices are shaped by environmental conditions, socioeconomic factors, and specific crop traits that satisfy both household consumption and market demand. The study suggests that climate shocks are not only agricultural issues but also create structural barriers to market integration for smallholders.

To promote inclusivity, competitiveness, and sustainability in global markets, targeted strategies such as climate-smart agriculture, improved financial access, customised training, and attention to crop traits like maize colour are vital for building resilience and enabling effective participation in global value chains. Policy measures must focus on building climate resilience as the foundation for fostering inclusive markets. Scaling up climate-smart agriculture (CSA) is key, especially through promoting drought-resistant maize varieties, conservation farming techniques, irrigation support, and integrated pest management. Extension services should deliver practical, climate-adaptive methods tailored to local conditions and market needs, helping smallholder farmers increase productivity while meeting global value chain demands. In addition, financial access is essential for enhancing the resilience of smallholders.

Tools like crop insurance and climate-adaptation credit lines are crucial for protecting farmers from climate-related shocks. These mechanisms protect incomes and stimulate investment in adaptive technologies, allowing farmers to manage risks more effectively and maintain long-term production despite climate uncertainty. Improving adaptive extension services is equally important. These should incorporate climate forecasting, digital platforms, and farmer-to-farmer learning networks, ensuring that the information and support provided are relevant, localised, and accessible. Such services arm farmers with the knowledge needed to make informed decisions on climate adaptation, boosting productivity and market access.

Climate change impacts are reducing yields and deepening systemic exclusion from global food systems, especially for smallholder farmers. Without integrating adaptation measures into agricultural and trade policies, these farmers risk further marginalisation. Therefore, climate resilience must be central to agricultural and trade policy frameworks to ensure smallholders remain competitive and integrated into global markets. Ultimately, building climate resilience in global value chains is vital for the long-term sustainability of smallholder farmers in sub-Saharan Africa. Expanding financial access, strengthening adaptive extension services, and promoting climate-smart agriculture can transform vulnerability into opportunity. These strategies will help smallholders participate more fairly and sustainably in regional and global markets, creating a more resilient agricultural sector in the face of climate change.

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