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Exploring the effect of climate change on food supply chains in Africa: a systematic review with a focus on South Africa

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Introduction: The food supply chain is a complex system encompassing multiple elements and stakeholders, spanning agricultural production to consumption, and is shaped by factors such as trade policies, food safety regulations, transportation logistics, labor availability, and global health crises. Addressing potential disruptions in food supply chains requires a keen focus on food availability, spanning production, distribution, and trade, emphasizing the urgency of proactive adaptation measures. The interconnection of food systems with geopolitical and environmental factors requires extensive adaptation strategies. Smallholder farmers are vulnerable to the effects of climate change as they depend on rain-fed agriculture, are exposed to climate variability, have limited access to markets and may lack technical knowledge, this negatively affects their overall income and participation in the food supply chain. Effective responses require collaboration among stakeholders at various levels to ensure the resilience and sustainability of food systems in the face of climate change. Understanding the complex interplay between climate change and the food supply chain is important for developing effective strategies to mitigate risks, enhance adaptation, and promote sustainability.
Methods: A systematic literature review was conducted across three databases: Web of Science, Scopus, and Google Scholar, to assess the impact of climate change on the food supply chain of smallholder farmers, focusing on livelihoods, food security, resilience, and adaptation strategies. The search included studies published in English from 1993 to 2023, employing Boolean operators to refine results with key terms such as “Climate,” “Change,” “Food Supply Chain,” “Smallholder Farmers,” and “Adaptation Strategies.” The initial search yielded 20,889 articles, which were screened for relevance based on their titles and abstracts. This process resulted in the exclusion of 10,585 articles from the study. The full texts of the remaining 10,304 articles were then reviewed. After the full-text screening process, 143 peer-reviewed studies were included in the study. The quality of each study was assessed using the Joanna Briggs Inventory (JBI) checklist, ensuring rigorous standards for bias reduction. The assessment followed PRISMA guidelines to enhance transparency and replicability. Data was imported into NVivo 12 for thematic analysis, identifying key themes pertaining to agricultural production, food safety, distribution, and resilience. This methodical approach provided a comprehensive overview of the impacts of climate change on smallholder farmers’ food supply chains.
Results: Nvivo12 was used for the screening process. After inputting the articles into NVivo 12, a manual review was conducted to check for any remaining duplicates. The files were imported into NVivo 12, and then sorted by tile and

author to bring potential duplicates next to each other. Thereafter the coding feature was used to tag the duplicates. A manual verification was then conducted, as NVivo does not allow for the automatic deletion of duplicates. The duplicates were then grouped and confirmed. Thereafter they were manually deleted from the project file. 26 articles from Web of Science, 20 from Scopus, and 97 from Google Scholar, totalling 143 articles were used in the systematic review. The production-to-consumption processes of the food supply chain are significantly affected by climate change. The shifts in temperature and rainfall influence the yields, quality, and harvest timing of crops. The extent of crop damage due to extreme weather events causes shortages and price hikes. Consumer demand, food safety, affordability, availability, and nutritional value are all impacted by the effects of climate change, which negatively affects the overall well-being of households. To overcome the challenges brought upon by this change in weather conditions, adaptation strategies which are actions taken to adjust the impacts of climate change and reduce the vulnerability to make farmers resilient are implemented. These include altered farming practices and water management. Mitigation strategies are also implemented, this is done to prevent or reduce causes of climate change. This consists of improving energy efficiency, reforesting and lowering greenhouse gases. These adaptation strategies vary depending on the region due to different climate conditions and land tenure. To adapt to the changes in the environment effectively throughout the supply chain, especially in crop production, the active laws and policies need to be reviewed.

Discussion: Overall, climate change disrupts food systems and exacerbates food insecurity, necessitating coordinated efforts such as the promotion of Climate-Smart Agriculture (CSA), providing access to financial services, Climate information systems, strengthening of food security programs and policies such as policies that promote agroecologic approaches to encourage the smallholder farmers to work with the ecosystems, market access, integration of climate and agricultural policy and trade policies and sustainable land policies to ensure sustainability and resilience, particularly in vulnerable regions. The multifaceted and urgent nature of the impact of climate change on food supply chains in Africa, notably South Africa, necessitates comprehensive attention and proactive measures to mitigate and adapt to the challenges posed. Effective responses require collaborative efforts among stakeholders at various levels to ensure the resilience and sustainability of food systems in the face of climatic uncertainty.

KEYWORDS

climate change, food supply chain, agricultural production, food security, adaptation

1 Introduction

Climate change signifies widespread alterations in temperature and atmospheric conditions, which significantly impact agricultural production and the global food supply chain (Burnham and Ma, 2016; Paloviita and Järvelä, 2019; Guo et al., 2019; Zavala-Alcívar et al., 2020). 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 and von Braun, 2013; Aung and Chang, 2014; Ivanov et al., 2017; Fan et al., 2021; Shah et al., 2021). Given the regional variability of these impacts, locally tailored mitigation and adaptation strategies are crucial (Awan et al., 2021; Rahman et al., 2022a, 2022b).

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). Studies by Kumari and Garg (2024) found that climate change exacerbates food insecurity, particularly among vulnerable populations, thereby weakening smallholder farmers' resilience and adaptive capacity to food supply chain disruptions. 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 and Dennis, 2012; Smith, 2020; Luo et al., 2022). 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; Kumar and Patel, 2025), as well as by external shocks such as the COVID-19 pandemic (Rasul, 2021;

TABLE 1 Research 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.

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 and Miura, 2023).

The broader scope of this systematic review, which examines climate change impacts on food supply chains across Africa with a focus on South Africa, is justified by the need to capture both regional diversity and interconnected vulnerabilities. While Africa as a whole faces climate-induced disruptions, ranging from production losses to infrastructure failures, South Africa offers a unique case of relatively advanced agricultural systems within a vulnerable continent. This dual focus allows for comparative insight and highlights cross-border interdependencies, especially in light of regional trade and continental policy frameworks such as the Comprehensive Africa Agriculture Development Programme (CAADP), which promotes agricultural growth and food security, and the African Continental Free Trade Area (AfCFTA), which aims to enhance intra-African trade. Thematically, it strengthens the review by linking climate science, food security, and policy responses across multiple scales.

Addressing these interconnected challenges requires a systems-thinking approach that integrates climate-smart agricultural practices, supportive policy frameworks, and technological innovation (Mandvi et al., 2024; Kumari and Agarwal, 2025; Kumari et al., 2025). 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 1.

2 Definition of terms

Resilience: the capacity of individuals, households, communities, or systems to anticipate, absorb, adapt to, and recover from the adverse effects of shocks and stresses—such as climate change, economic disruptions, or natural disasters—while maintaining or improving their essential functions, structures, and identity (FAO, 2015).

Food security: exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. It comprises four key dimensions: availability, access, utilisation, and stability (FAO, 2008).

Adaptation strategies: refer to the specific actions, practices, and adjustments made by individuals, communities, institutions, or systems in response to actual or expected climatic stimuli or their effects. These strategies aim to moderate harm or exploit beneficial opportunities, particularly in the context of reducing vulnerability and enhancing resilience to climate change in agriculture and food systems (IPCC, 2022).

Livelihoods: encompass the capabilities, assets (both material and social), and activities required for a means of living. A livelihood is considered sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, and provide sustainable income opportunities without undermining the natural resource base (Chambers and Conway, 1992).

Climate change: refers to a long-term alteration in temperature, precipitation, wind patterns, and other elements of the Earth's climate system. In the agricultural context, it includes both anthropogenic (human-induced) and natural drivers that influence food production, water availability, and ecosystem stability (IPCC, 2021).

Food supply chain: comprises all the processes involved in the production, processing, distribution, and consumption of food. In agriculture, this includes input suppliers, farmers, post-harvest handlers, processors, transporters, retailers, and consumers. The chain is vulnerable to disruptions caused by climate change, such as extreme weather events, pest outbreaks, and infrastructure damage (Garnett, 2011).

Agriculture: is the practice of cultivating soil, growing crops, and raising animals for food, fibre, fuel, and other products essential to sustaining life. It is a critical sector for economic development, rural livelihoods, and food security, and is highly sensitive to climate variability and long-term climate change (FAO, 2013).

Smallholder farmers: are agricultural producers operating on relatively small plots of land, typically relying on family labour and limited external inputs. They often face constraints such as limited access to markets, finance, and technology, making them especially vulnerable to climate change impacts (HLPE, 2013).

3 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.

3.1 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 peer-reviewed articles to ensure broad coverage of the relevant literature. Pre-defined keywords and exclusion and inclusion criteria were applied to ensure that pertinent articles related to the research question were included in the systematic review (Arksey and O'Malley, 2005).

3.2 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 they met the inclusion criteria, as outlined in section 3.3.

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" were used to broaden the search. A total of 20,889 articles were initially identified by applying this search strategy across databases. This extensive 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 QRS NVivo 12 for qualitative data analysis (Dhakal, 2022). NVivo 12 was used to enhance 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 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:

3.2.1 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")).

3.2.2 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")).

3.2.3 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 and2023.

3.3 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 effects 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, limited to peer-reviewed studies published between 1993 and 2023.

TABLE 2 Inclusion and exclusion criteria used in the study to select the 143 articles for the systematic review.

Criteria	Inclusion	Exclusion
Study focus	Impact of climate change on the food supply chain	Studies not addressing climate change impacts on the food supply chain
Outcome variables	Impacts on different components of the food supply chain	Outcomes not related to the 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

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. The researcher screened papers for relevance based on title and abstract,. Papers focusing on Africa and South Africa were prioritised over those that centred 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 utilised in this study are summarised in Table 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 excluded. The full texts of the remaining 10,304 articles were then assessed for further eligibility, leading to the removal of 10,161 articles due 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 1).

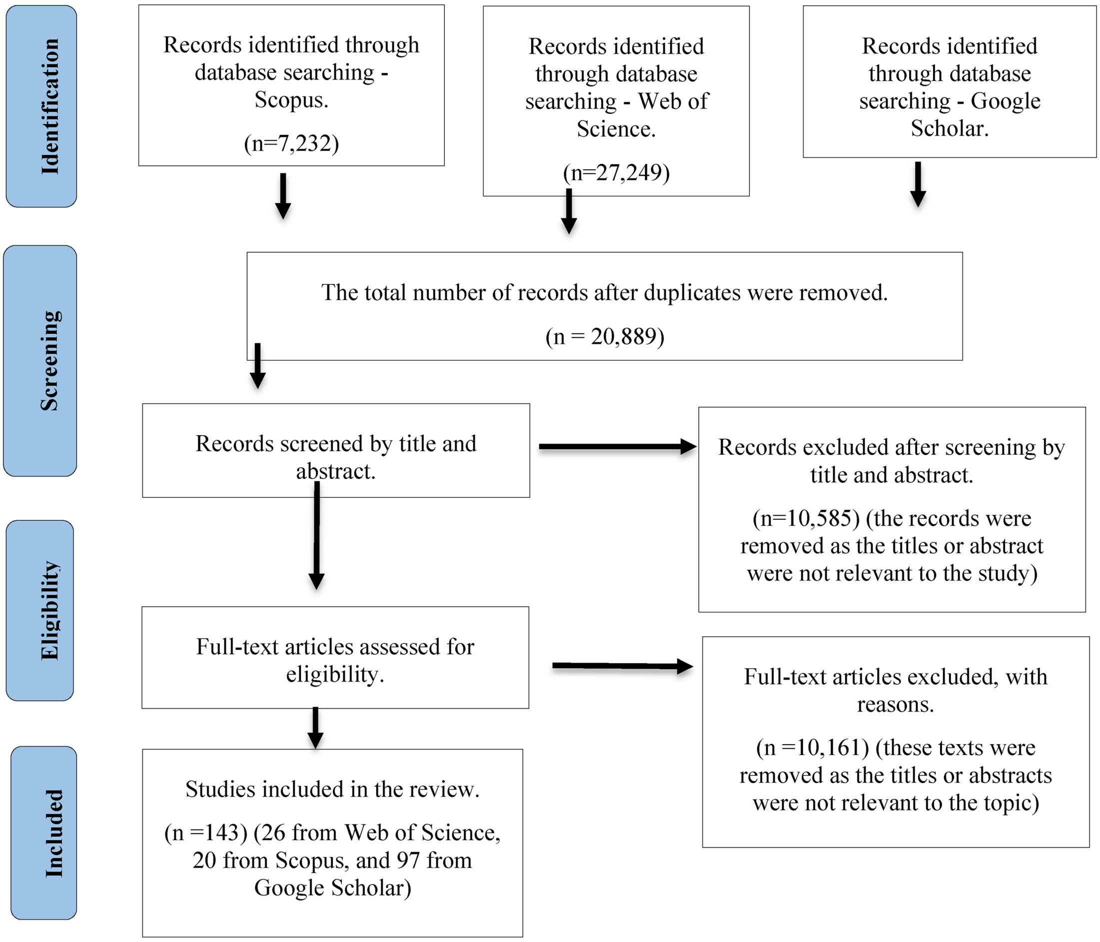

FIGURE 1
PRISMA flow chart showing the literature search procedure for this systematic review.

3.4 Risk of bias assessment

Each identified study used in this systematic review was assessed for bias using the JBI checklist (Munn et al., 2015), as illustrated in Table 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 et al., 2015). The researcher scanned the articles to determine whether they met the eligibility criteria. The studies were then checked using the JBI and PRISMA Guidelines 2020 checklists.

A dual review was conducted by two researchers to reduce selection bias. The authors and journal names were blinded during the review to limit potential bias. The process outlined above was used to reduce and control for bias in this study. Only 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 et al., 2015). This systematic approach allowed for a robust selection of studies that aligned with the review objective, investigating the impact of climate change on various components of the food supply chain of smallholder farmers.

A risk of bias assessment was conducted on all 143 included studies using the JBI checklist. The majority of studies (85%) met over 80% of the JBI criteria, indicating high methodological quality. Key strengths observed included clearly stated research objectives, well-defined inclusion criteria, and appropriate data analysis methods. However, a small proportion of studies (approximately 10%) showed unclear reporting on sample size justification or ethical considerations, which were noted as minor risks but retained due to their thematic relevance. The results of the bias assessment are summarised in Table 3, which outlines the distribution of quality scores across the reviewed studies.

Potential biases, such as language and database bias, were acknowledged and addressed throughout the review process. To reduce language bias, the review was limited to English-language studies, which is a common constraint but was necessary due to resource limitations. Database bias was mitigated by using three diverse and reputable sources: Web of Science, Scopus, and Google Scholar, to ensure comprehensive coverage of peer-reviewed literature. Additionally, duplicate records were manually removed, and a dual-reviewer screening process was employed to enhance objectivity and minimise selection bias.

TABLE 3 Joanna Briggs inventory (JBI) checklist used in the study.

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

3.5 Quality assessment

Quality assessment of the studies identified using the three databases was conducted following the PRISMA guidelines and checklist, as shown in Table 4 (Shamseer et al., 2015). This was performed to ensure a transparent, systematic evaluation process. An independent reviewer evaluated the quality of each articles included in the study and removed those that were not eligible based on the inclusion and exclusion criteria mentioned in Section 3.3.

The PRISMA guidelines, as seen in Figure 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 on 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, enhancing 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 illustrates the analytical process used in this study.

Inter-rater reliability was ensured by having multiple researchers independently code a subset of the data using NVivo. The coding outputs were then compared and discussed to resolve discrepancies and achieve consensus on code definitions and application. This iterative process improved coding consistency and enhanced the trustworthiness of the qualitative analysis.

To ensure transparency in the selection process, the 20,889 initial records were screened through a multi-stage process based on PRISMA-P guidelines. Titles and abstracts were first reviewed for relevance to the research question. Irrelevant studies, duplicates, and those not meeting the inclusion criteria were excluded, resulting in 10,304 full-text articles assessed for eligibility. Of these, only 143 met all criteria, specifically a clear focus on climate change impacts on food supply chains in Africa (with emphasis on South Africa), relevance to at least one of the outcome themes, and methodological rigour as determined by the JBI and PRISMA checklists. While Google Scholar was included to ensure broader coverage and capture grey literature and hard-to-find peer-reviewed articles, we mitigated the risk of bias by limiting the selection to peer-reviewed journal articles only and cross-validating relevance through Scopus and Web of Science. This triangulation approach reduced over-reliance on any single database and enhanced the comprehensiveness and credibility of the final sample.

The final selection of 143 articles was based on a rigorous multi-phase screening process that combined relevance scoring and quality assessment. Articles were first screened for thematic alignment with the review objectives, focusing on the impact of climate change on various components of the food supply chain in Africa and South Africa. Studies that met the initial relevance threshold were then subjected to quality appraisal using the JBI checklist and the PRISMA 2020 guidelines. Only studies that demonstrated methodological soundness, such as clearly defined research objectives, appropriate study design, valid outcome measures, and transparent data analysis,

TABLE 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 synthesising 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

were included. This dual-layer approach ensured that the final pool of studies was both thematically relevant and of high academic quality, thereby enhancing the reliability and validity of the review findings.

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

3.6 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 3. These themes guided the results of this systematic review. The thematic analysis using NVivo 12 followed a systematic coding process. Initially, a coding framework was developed based on the research questions and preliminary readings of the included articles. Two independent coders applied this framework to the dataset to ensure consistency and reduce subjective bias. Inter-coder reliability was assessed through regular meetings where coding discrepancies were discussed and resolved through consensus, refining the coding scheme as necessary. This iterative process ensured that themes such as agricultural production, processing, distribution, and adaptation strategies were accurately and reliably identified, providing a robust basis for the review findings.

3.7 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

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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 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. The selected studies primarily focused on sub-Saharan Africa, with particular emphasis on South Africa and its smallholder farming communities. This geographical concentration aligns with the objectives of the review and is reflected in both the inclusion criteria and the results, ensuring contextual relevance to the study's focus on climate change impacts within African food systems.

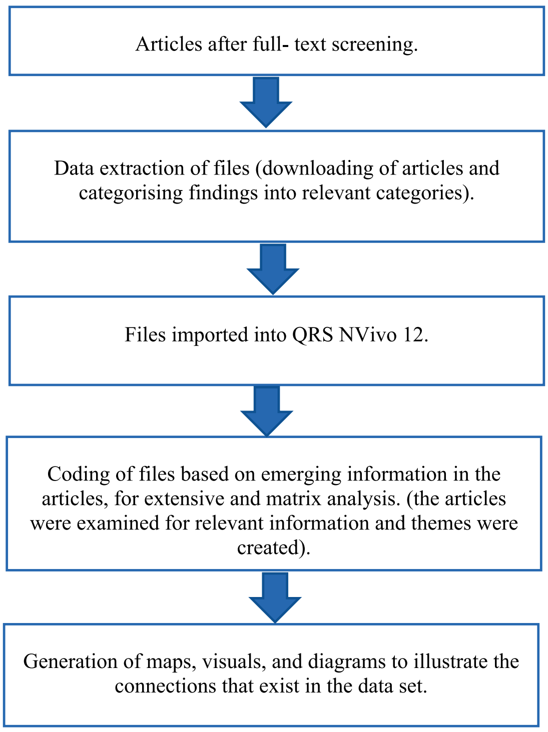

FIGURE 2
The data analysis process was implemented for the articles that met the inclusion criteria.

4 Results

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

4.1 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

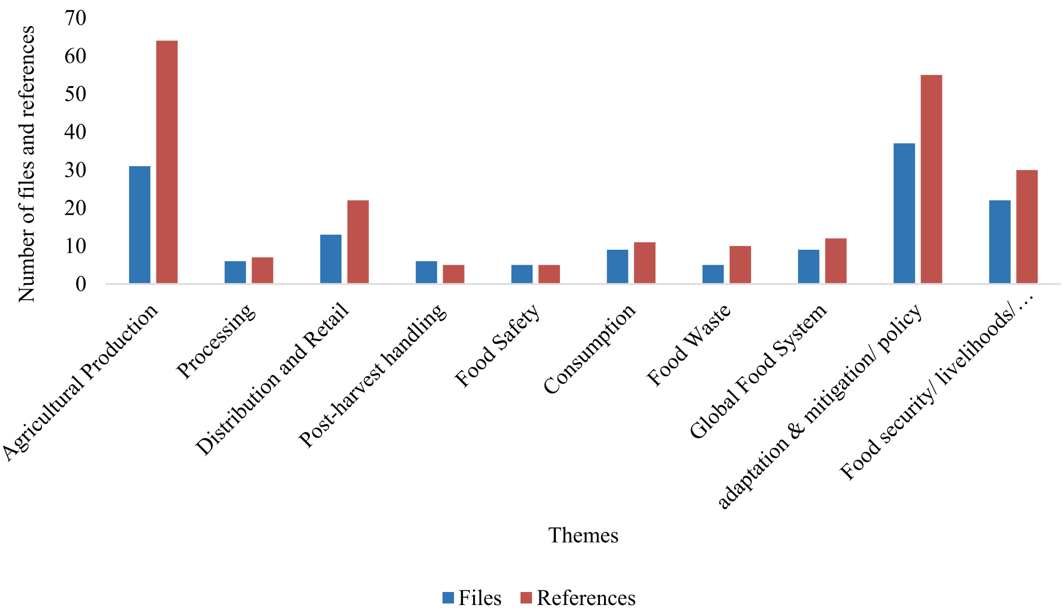

FIGURE 3
Themes identified from the NVivo analysis (own analysis).

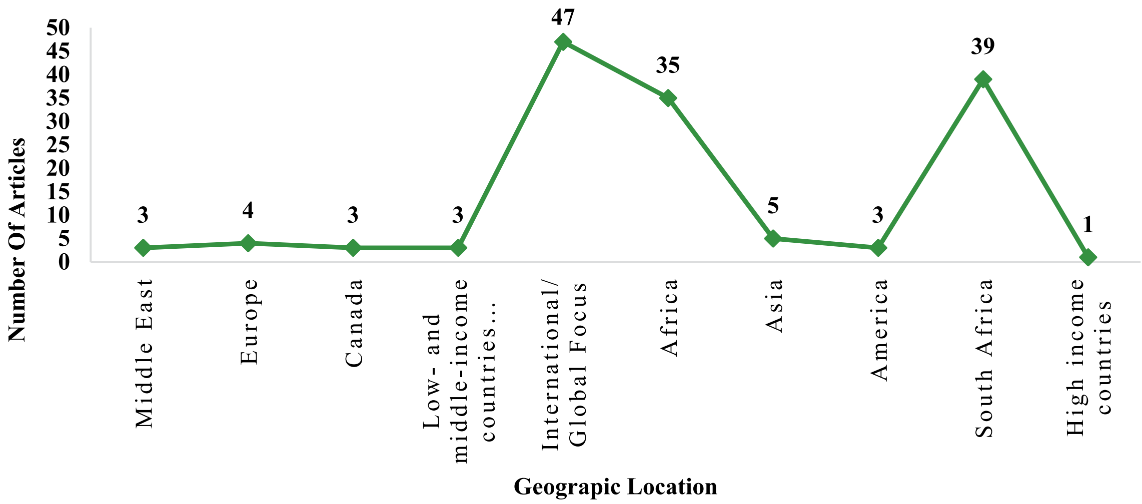

FIGURE 4
Geographic location of papers used in the study.

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. This review examined the multifaceted impacts of climate change across all stages of the food supply chain, from agricultural production to consumption, highlighting interconnected vulnerabilities and adaptation responses. Agricultural production emerged as the most extensively studied sector, with 31 articles reporting significant yield reductions in rain-fed agriculture across Africa and South Africa, estimated at around 50% between 2000 and 2020 (Challinor et al., 2007; Brown et al., 2009). These impacts were particularly severe for staple crops in drought-prone regions, emphasising the heightened vulnerability of rain-fed smallholder systems compared to irrigated or commercial farms (Castro et al., 2016; Mkuhlani et al., 2022). Water scarcity and ecosystem degradation further exacerbate production challenges, intensifying food insecurity (Gbetibouo et al., 2010; Ribeiro and Rodriguez, 2020).

Adaptation and mitigation strategies, discussed in 37 studies, varied significantly by region and crop type. In Southern Africa, smallholder farmers commonly employed diversification of crops, drought-resistant varieties, and adjusted planting calendars to cope with shifting rainfall patterns (Mthembu and Hlophe, 2021; Bijani et al., 2020). Conversely, in West African contexts, some studies highlighted reliance on traditional knowledge and community-based resource management, reflecting localised adaptive capacity differences (Rurinda et al., 2015). Policy interventions supporting climate-smart agriculture and infrastructure improvements were identified as critical enablers of effective adaptation, particularly where institutional support was strong (Brown et al., 2009; Mthembu and Hlophe, 2021). Beyond production, climate change-induced disruptions in distribution and retail were reported in 13 studies, with increased frequency of extreme weather events damaging transport networks and storage facilities (Dasaklis and Pappis, 2013; Odimegwu, 2022). The COVID-19 pandemic further exacerbated these vulnerabilities by triggering food shortages and price volatility, disproportionately affecting urban and peri-urban consumers (Khan et al., 2020; Mishra et al., 2021). These disruptions illustrate the compounded risks that climate change and other systemic shocks pose to supply chain resilience. Consumption-level impacts, addressed in nine studies, revealed decreased food availability and affordability, resulting from yield losses and supply chain delays (Ronquest-Ross et al., 2015; Amoah and Simatele, 2021). These effects disproportionately impacted vulnerable populations in rural and low-income urban areas, underlining the social dimensions of climate-induced food insecurity (Tshikovhi and Wyk, 2021). Similarly, food safety concerns intensified as climate change increased the prevalence of foodborne pathogens and contamination risks, affecting consumer confidence and health outcomes (King et al., 2017; Lake and Barker, 2018; Kwame et al., 2022; Mazi et al., 2023). Additional sectors such as processing, post-harvest handling, and food waste also experienced climate-related stressors. For instance, floods and temperature extremes damaged processing and storage infrastructure, causing bottlenecks and price hikes (Paloviita and Järvelä, 2019; Amicarelli and Bux, 2020; Machate, 2020; Meyer, 2020). Post-harvest losses and food waste increased due to reduced shelf life and handling delays, with implications for food availability and environmental sustainability (Simba et al., 2017; Oelofse et al., 2018; Angula et al., 2022). These findings underscore the importance of integrated supply chain approaches to comprehensively address climate vulnerabilities.

While Figure 5 highlights the distribution of articles across key themes, notable gaps emerge in areas such as food safety, which is underrepresented despite its critical importance. This scarcity may be due to limited research focus on the intersection of climate change and food safety in Africa and South Africa, possibly reflecting challenges in data availability, funding priorities, or the complexity of linking climate impacts directly to foodborne illnesses. The underrepresentation suggests an important research gap, emphasising the need for future studies to explore how climate-driven changes in pathogen prevalence, contamination risks, and food handling

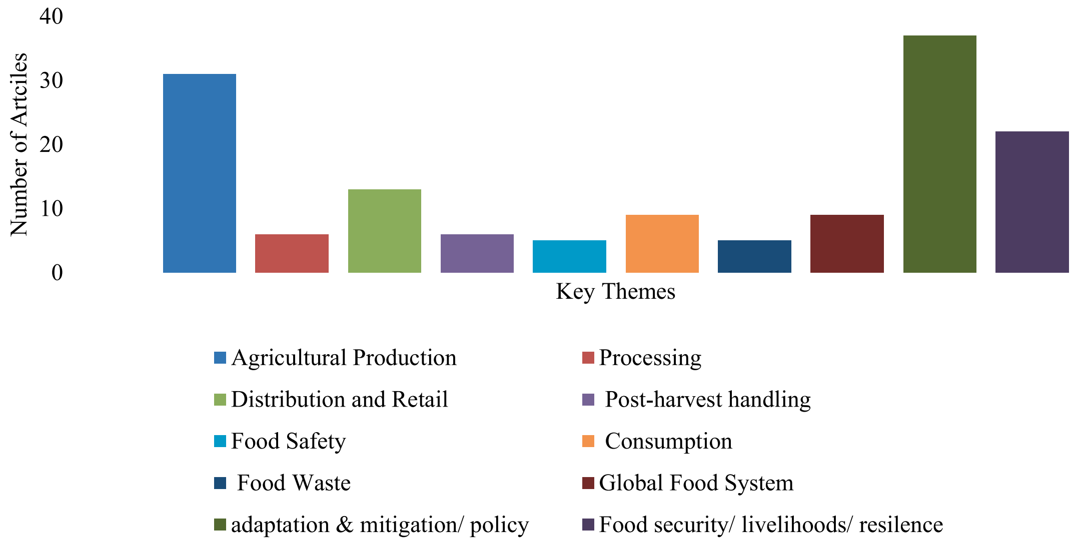

FIGURE 5
Key themes on how climate change impacts the food supply chain.

practices affect consumer health and confidence. Addressing this gap is vital for developing comprehensive climate adaptation strategies that encompass the entire food supply chain, including food safety considerations.

4.2 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 wellbeing 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 6.

As illustrated in Figure 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 marginalised 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 and Ayiemba, 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 and Filippelli, 2022; Manoj et al., 2023).

The cascading effects of climate change were found to negatively 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 (Assan, 2022; Farooq et al., 2022; Hedlund et al., 2022). Declines in agricultural productivity ultimately lead 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; Berhanu and Wolde, 2019; 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; Bezares et al., 2021). These impacts increase the likelihood of food unaffordability and hunger, particularly among vulnerable populations (Oelofse and Nahman, 2012; Hendriks and Olivier, 2015; Akil and Ahmad, 2023). Figure 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 and Peter, 2007; Averbeke and Khosa, 2018; Dinesh et al., 2021; Mthembu and Hlophe, 2021).

Moreover, the persistence of climate shocks without adequate adaptation responses is projected to exacerbate rural poverty and deepen food insecurity (Sithole, 2019; 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 and Wright, 2019; Teressa, 2021; Guo, 2023). Without timely and targeted interventions,

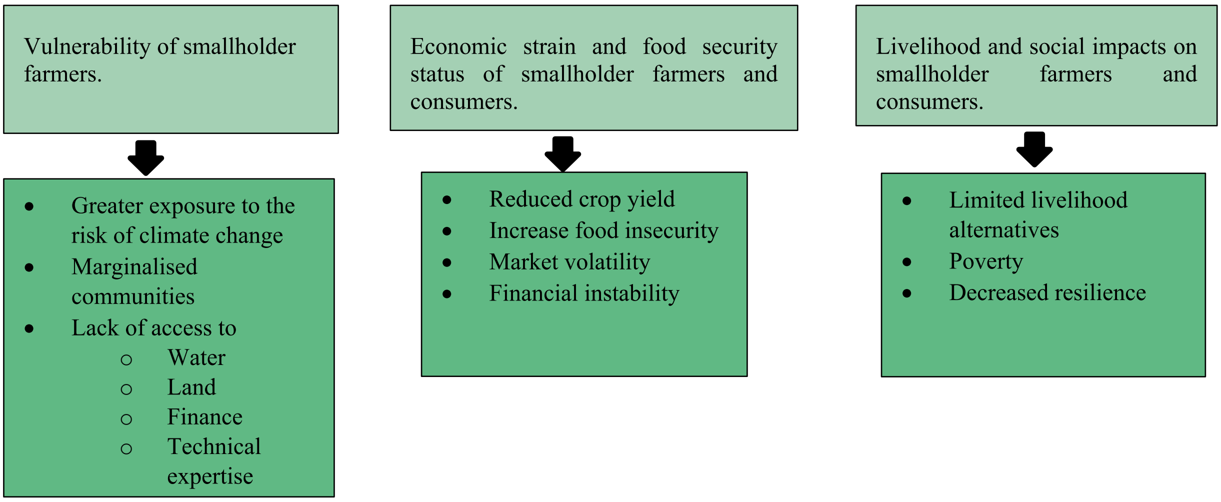

FIGURE 6
Impacts of climate change on the livelihoods and food security of smallholder farmers that emerged from the review.

climate change will continue to erode the resilience of both producers and consumers, worsening national food security indicators and impeding progress towards climate-resilient agricultural systems (Singh et al., 2014; Myers et al., 2017; Mohtar and Fares, 2022; Guo, 2023).

The literature reveals clear trends and critical gaps in understanding the full extent of climate change impacts on smallholder vegetable farming and the broader food supply chain. While many studies document the heightened vulnerability of smallholder farmers due to limited resources and exposure to climate variability, there is comparatively less research on effective, context-specific adaptation strategies that can mitigate these risks, especially in marginalised rural communities. Additionally, the cascading effects of climate shocks on market stability, food prices, and consumer access remain underexplored, limiting comprehensive policy responses.

These gaps have significant implications: without addressing barriers such as inadequate water access, financial exclusion, and lack of technical support, the resilience of smallholder farmers will continue to decline, deepening food insecurity and livelihood instability. The insufficient focus on post-production stages and supply chain linkages restricts understanding of systemic vulnerabilities, which is crucial for designing holistic climate-resilient food systems. Consequently, bridging these research gaps is essential for developing targeted interventions that safeguard both producer livelihoods and consumer food security, particularly in vulnerable African contexts where the socio-economic repercussions of climate change are most severe. 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 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 the supply chain, public health and livelihoods, and infrastructure resilience, each cited in four articles (Mugambiwa and Tirivangasi, 2017; Suebsombut et al., 2017; Molieleng et al., 2021; Chen et al., 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 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.

The systematic review reveals a diverse array of climate change adaptation and mitigation strategies aimed at reducing vulnerabilities within the food supply chain, particularly for smallholder farmers.

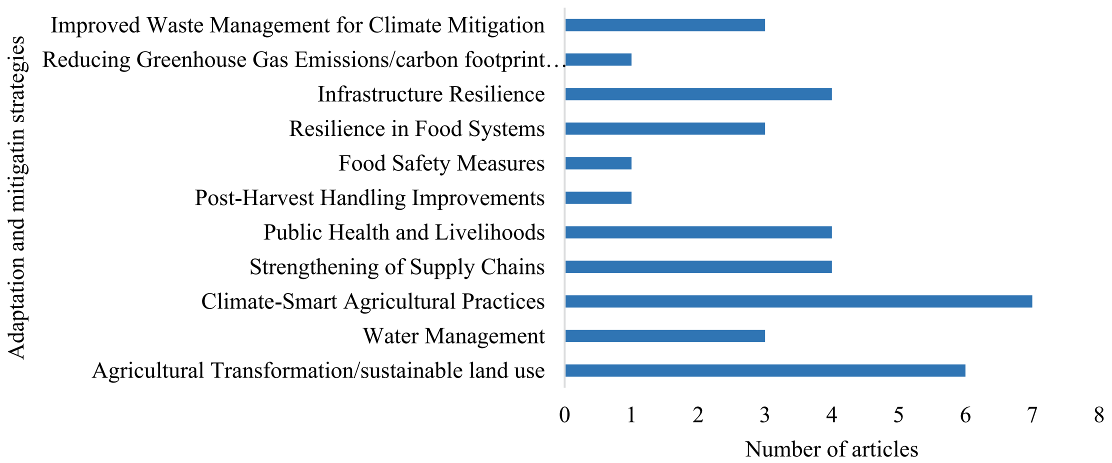

FIGURE 7
Adaptation and mitigation measures that emerged from the review.

Thematic analysis highlights a predominant focus on climate-smart agriculture, which integrates innovative farming practices to enhance productivity and resilience under changing climatic conditions (Suebsombut et al., 2017; Molieleng et al., 2021; Chen et al., 2022). Closely related are strategies centred on sustainable land use and agricultural transformation, reflecting an emphasis on resource-efficient and ecologically sound production methods (Ramirez-Villegas et al., 2012; Klausbruckner et al., 2016; Baninla et al., 2022). Complementary approaches such as supply chain strengthening, infrastructure resilience, and public health measures illustrate an expanding recognition of systemic and socio-economic factors influencing food system stability (Musvoto et al., 2015; Mwadzingeni et al., 2022; Hecht and Neff, 2019).

Despite this breadth, several critical gaps emerge. Notably, the literature shows limited geographical specificity, with relatively few studies contextualising these strategies within South Africa or similar African smallholder settings, where resource constraints and institutional challenges differ markedly from global contexts (Kaudia et al., 2022). Moreover, integration of policy frameworks with on-the-ground adaptation practices is underexplored, weakening the translation of evidence into actionable interventions (Brouder and Gomez-Macpherson, 2014). The relatively sparse attention to post-harvest handling and waste management within adaptation discourse further suggests a need for more holistic approaches encompassing the entire supply chain beyond production (Nelson et al., 2016; Baninla et al., 2022; Gerken and Morrison, 2022). These trends imply that while considerable progress has been made in identifying viable climate-resilient agricultural practices, there remains an urgent need for context-specific, multi-scalar adaptation pathways that combine technological innovation with enabling institutional and policy environments. Strengthening linkages between policy design, farmer capacity building, and infrastructure investment will be crucial to enhancing food system resilience and sustainability in climate-sensitive regions such as rural KwaZulu-Natal (Suebsombut et al., 2017; Molieleng et al., 2021; Kaudia et al., 2022).

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 (Gregory et al., 2005; Brouder and Gomez-Macpherson, 2014; Hecht and Neff, 2019; Kaudia et al., 2022).

4.3 Policy recommendations

The reviewed literature highlights a wide range of policy recommendations essential for strengthening the resilience of smallholder vegetable farming systems in South Africa and the broader African context, where these farmers are critical to food production yet remain highly vulnerable to climate change impacts. As illustrated in Figure 8, two dominant policy themes emerged prominently: enhancing climate information systems and increasing targeted support for smallholder farmers. Improving climate information systems requires more than generic weather forecasts; it demands localised, timely, and accessible climate services tailored to South Africa's and the broader African context's diverse agro-ecological zones and cropping calendars. This specificity is vital for smallholder vegetable farmers, who rely heavily on natural rainfall and face narrow planting windows, to make informed decisions regarding sowing, irrigation, and harvesting (Lengnick et al., 2015; Burnham and Ma, 2016; Chandra et al., 2018). Policy must therefore support the development and dissemination of climate advisories through multiple channels, including mobile platforms and community extension networks, ensuring inclusion of marginalised farmers with limited access to technology.

Figure 8 also quantitatively summarises the frequency of key adaptation and mitigation strategies discussed in the literature, revealing a concentration of research attention on climate-smart agricultural practices and sustainable land use, with 7 and 6 articles, respectively, focusing on these areas. Other important but less emphasised strategies include strengthening supply chains, infrastructure resilience, public health and livelihoods, as well as waste management and food safety measures. This distribution points to existing gaps in policy and research, particularly around underrepresented areas such as food safety and greenhouse gas emissions reduction. South Africa-specific policy responses should

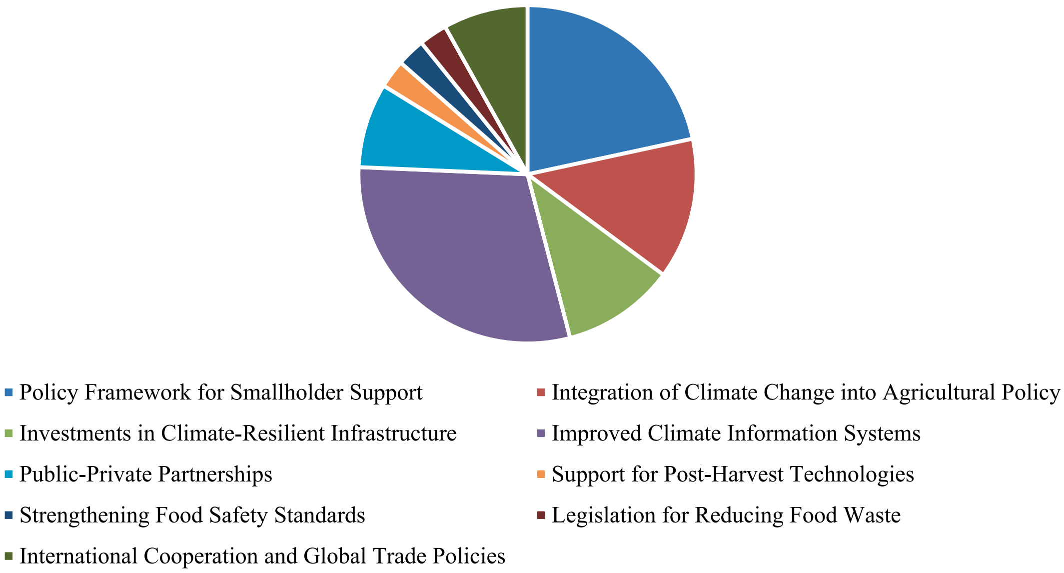

FIGURE 8
Policy recommendations from the reviewed articles.

therefore broaden focus beyond production-level adaptation to incorporate systemic resilience across the supply chain, including post-harvest handling, food safety regulations, and waste management initiatives (Duchenne-Moutien and Neetoo, 2021; Molieleng et al., 2021; Chen et al., 2022; Mehmood et al., 2022; Osei et al., 2023). Institutional support frameworks should expand to provide climate-resilient inputs, decentralised extension services, and investment in infrastructure such as irrigation and cold storage, tailored to smallholder contexts (Thow et al., 2018; Chakwizira, 2019; Wyk, 2022; Zinyengere et al., 2013). Moreover, fostering public-private partnerships and regional cooperation will be vital to enhancing market access, supply chain stability, and trade resilience, ensuring food affordability and availability in a changing climate (Ayanlade et al., 2022; Lee and Gambiza, 2022; Murken and Gornott, 2022). Collectively, these targeted and integrated policy measures, informed by the thematic patterns illustrated in Figure 8, provide a strategic pathway to build the adaptive capacity of South African smallholder vegetable farmers and strengthen national food security in the face of climate challenges.

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

5 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 and 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 (Terdoo and 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 and Pappis, 2013; Pittelkow et al., 2015; Paloviita and 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., 2022a, 2022b). 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 and 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 and Verburg, 2017;

Mkuhlani 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 (Müller et al., 2011; Blanc, 2012; Berti and Mulligan, 2016). The review highlights that informal markets and local food systems play a crucial role in buffering climate shocks, particularly for smallholder farmers. These systems offer flexible, low-barrier platforms for trade, provide alternative income sources, and ensure continued food access when formal supply chains are disrupted (Amelework et al., 2021; Zia et al., 2022). By supporting localised adaptation and reducing dependence on centralised markets, informal food systems contribute significantly to community resilience in the face of climate-related disruptions.

Climate-smart agricultural practices emerged in 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 and Tubiello, 2007; Tubiello et al., 2007; Willett, 2021; Pereira and Hawkes, 2022; Oduniyi and 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; Paganini et al., 2020; Atwoli et al., 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. The review identified notable differences between low-income and middle-income countries regarding vulnerability and resilience to climate change. Low-income countries generally exhibited higher vulnerability due to weaker institutional capacity, limited infrastructure, and fewer adaptation resources (Porter et al., 2016; Umar, 2023). In contrast, middle-income countries such as South Africa demonstrated relatively greater resilience, though significant vulnerabilities persist, particularly among marginalised smallholder farming communities (Parfitt et al., 2010). These distinctions help contextualise the findings within broader socio-economic frameworks.

Temporal trends observed across the reviewed studies from 1993 to 2023 reveal a shift in focus from primarily assessing the impacts of climate change to emphasising adaptation strategies and resilience-building, particularly within smallholder food supply chains. While earlier research centred on documenting climate-related vulnerabilities, more recent studies increasingly highlight practical adaptation interventions and the integration of policy frameworks. This evolution reflects a growing urgency to implement actionable solutions in response to climate threats, as detailed in the results section.

To address the vulnerabilities identified in the vegetable supply chain, especially within the South African context, several targeted policy interventions are warranted. The reviewed literature consistently highlights the importance of strengthening food governance, developing post-harvest technologies, and improving waste management systems, key areas for mitigating the impacts of perishability and spoilage, which disproportionately affect smallholder vegetable farmers (Conway et al., 2015; Ahenkan, 2019; Grote et al., 2021; Dunjana et al., 2022).

Improved food governance is essential and aligns with South Africa's National Climate Change Adaptation Strategy (NCCAS, 2020), which emphasises coordinated institutional action and inclusive governance to enhance resilience across agricultural value chains. Strengthening policy implementation across government tiers can empower smallholder farmers by improving their access to resources, climate information, and decision-making platforms.

Investment in post-harvest technologies is also critical, as recommended in the Department of Agriculture, Forestry and Fisheries Strategic Plan 2020–2025 (DAFF, 2020). Introducing innovations such as cold storage, improved packaging, and value-added processing can significantly reduce post-harvest losses, extend shelf life, and improve market opportunities, particularly for resource-constrained smallholders.

Effective waste management is another priority area and is supported by South Africa's National Waste Management Strategy (DEA, 2019), which promotes circular economy principles. Improved recycling systems, composting of organic waste, and resource recovery within the vegetable supply chain can reduce environmental degradation while generating additional income streams for rural producers.

Furthermore, promoting sustainable production practices and reducing dependency on costly external inputs aligns with the objectives of the National Development Plan 2030 (NPC, 2012) and the Integrated Resource Plan (Republic of South Africa, 2019). Support for agroecological methods, organic inputs, and water-efficient irrigation technologies can enhance smallholder resilience by improving soil health, reducing climate vulnerability, and fostering long-term sustainability.

These policy-aligned recommendations present a coherent framework for addressing structural and climate-induced challenges in the vegetable supply chain. Their effective implementation is vital to safeguarding smallholder livelihoods and enhancing food security in rural South African communities. 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 and Olivier, 2015; Masipa, 2017; Kochan and Nowicki, 2018; Reza and Sabau, 2022).

To operationalise these policy recommendations, it is essential to prioritise context-specific, actionable interventions. For instance, expanding climate-smart agriculture (CSA) training programmes in KwaZulu-Natal can provide smallholder farmers with adaptive techniques for managing climate risks, improving water efficiency, and enhancing soil health (FAO, 2013). Establishing decentralised post-harvest handling hubs and improving local market infrastructure can also directly reduce losses, increase shelf life, and stabilise farmer incomes (DAFF, 2020; Romero-Perdomo et al., 2022). These localised, implementable steps are vital for translating national policy frameworks into practical benefits for smallholder farmers and enhancing food system resilience in vulnerable regions.

While the proposed interventions such as climate-smart agriculture (CSA) offer significant potential for enhancing resilience in smallholder vegetable systems, their feasibility remains constrained by several contextual challenges. Key barriers include limited access to finance, high upfront costs of adopting CSA technologies, and knowledge gaps among farmers regarding climate-resilient practices (Kurukulasuriya and Mendelsohn, 2008; Kaptymer et al., 2019; Umar, 2023). Additionally, resistance to change due to entrenched farming traditions, mistrust of new technologies, and lack of institutional support can further hinder uptake (FAO, 2013). For CSA and related solutions to be viable, targeted support is required, including the provision of subsidies or credit schemes for low-income farmers, integration of CSA modules into existing agricultural extension programmes, and the establishment of farmer field schools to encourage peer-to-peer learning (FAO, 2013). Strengthening multi-stakeholder collaboration between government, NGOs, and the private sector is also critical to building trust and ensuring that interventions are culturally appropriate and economically accessible. Without addressing these systemic barriers, the implementation of climate adaptation strategies will remain uneven and limited in impact.

South Africa's high levels of economic inequality exacerbate the impacts of climate change more severely than in many neighbouring countries. While nations such as Botswana and Namibia also face climate-related agricultural challenges, their smaller populations and relatively more equitable access to resources often result in more coordinated responses (Khee et al., 2014; World Bank, 2021). In contrast, South Africa's deeply entrenched socio-economic disparities limit the adaptive capacity of marginalised groups, particularly smallholder farmers who lack access to land, credit, and technical support (Ziervogel et al., 2014; Shisanya and Mafongoya, 2017; Semenya, 2023). This uneven vulnerability underscores the need for climate adaptation policies that are not only technically sound but also socially inclusive.

6 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, few studies explicitly address post-harvest losses in South Africa, despite their critical impact on supply chain efficiency and farmer incomes. The absence of integration across sectors like agriculture, water, energy, and food safety was also 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 resilence of the food supply chain 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. Longitudinal studies on climate-smart agriculture adoption and its socio-economic impacts would provide valuable insights into the sustainability of adaptation strategies over time. These areas remain underexplored yet hold significant potential for informing more context-specific and inclusive climate responses.

By systematically identifying both established knowledge and critical gaps, this review lays the groundwork for future research on climate change impacts in South Africa's vegetable supply chains. The findings highlight areas requiring further empirical investigation, including post-harvest losses, market dynamics, gender influences, and governance factors that affect smallholder adaptation. This focused synthesis provides a clearer understanding of the challenges and opportunities for building resilience, informing policymakers and researchers aiming to develop more targeted and effective climate adaptation strategies.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

MN: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing. DN: Writing – review & editing. RS: Writing – review & editing. MSCN: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1604839/full#supplementary-material

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