



REVIEW ARTICLE

Climate change perception and adoption strategies in agriculture: A bibliometric literature review

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Abstract

Climate change is transforming farming systems across the world and how farmers perceive and respond to these changes is key to future food security. This study examines global research on climate change perception and agricultural adoption through an integrated bibliometric and systematic review of 117 Scopus-indexed publications selected using preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. Bibliometric analyses conducted with RStudio and VOSviewer reveal a sharp post-2020 rise in publications, indicating growing scientific and policy attention to farmer-centred resilience. Keyword and network structures show that adoption research is anchored around farmer perception, adaptive capacity, food security and climate-smart practices, reflecting the strong integration of social and biophysical perspectives. The review identifies seven major adoption pathways: crop diversification, climate-resilient crop varieties, water and soil management, farm management adjustments, livelihood diversification and institutional and information support. These strategies are widely adopted because they directly reduce risk under heat stress, rainfall variability, droughts and floods. Perception analysis indicates that farmers most strongly associate climate change with rising temperature (20 %) and rainfall variability (18 %), showing that adoption is primarily triggered by observable, experience-based stresses. However, the translation of perception into action depends on access to extension, finance and climate information. Strengthening inclusive support systems and context-specific innovations is therefore essential for scalable and durable agricultural resilience.

Keywords: adoption strategies; climate change; climate-smart agriculture; perception level; smallholder farmers

Introduction

Agriculture remains a foundational pillar of rural livelihoods and food security, particularly in developing and agrarian economies, where a substantial share of the population depends directly or indirectly on farming for income and employment (1). Historically, agricultural development has prioritised productivity growth to meet rising food demand driven by population expansion, urbanisation and changing consumption patterns (2). While technological advances and intensification strategies have significantly increased output in many regions, they have also heightened agriculture's exposure to environmental stresses and resource degradation (3). As a result, contemporary agricultural systems now face the dual challenge of sustaining productivity while adapting to rapidly changing climatic conditions.

Climate change has emerged as one of the most critical external pressures shaping global agriculture, altering temperature regimes, rainfall patterns and the frequency of extreme weather events such as droughts, floods and heat waves (4). These changes directly affect crop growth, soil moisture, water availability, pest dynamics and farm profitability, thereby

increasing uncertainty in key farm-level decisions related to crop selection, sowing time, irrigation scheduling, input use and harvesting practices (5). Unlike gradual environmental change, climate variability is increasingly experienced by farmers as repeated and visible disruptions, making climate change a lived reality rather than a distant scientific concern (6).

Farmers' perception of climate change plays a pivotal role in shaping how these climatic signals are interpreted and responded to at the farm level (7). However, climate perception is not uniform across regions, as farmers' responses are shaped by local agro-ecological conditions, production systems, institutional support and previous exposure to climatic stress. Evidence from semi-arid and climate-sensitive regions, particularly in parts of Sub-Saharan Africa and South Asia, shows that farmers who frequently experience droughts, irregular rainfall, heat stress and floods are more likely to perceive climate change as an immediate threat to agricultural production and livelihoods (8). Empirical evidence from diverse agroecological regions shows that higher levels of climate awareness are often associated with adaptive farm responses (9–11). These include crop diversification, improved crop varieties, water and soil management and farm management

adjustments. However, perception alone does not automatically translate into action; access to information, institutional support, financial resources and extension services strongly mediate the adoption process (12, 13).

Over the past two decades, research on climate change adaptation in agriculture has expanded considerably and evolved into a more interdisciplinary field integrating social, behavioural, agronomic and environmental perspectives (14–16). Earlier studies primarily focused on understanding farmers' climate perceptions and risk awareness, whereas more recent research increasingly emphasises adaptive capacity, institutional support, resilience-building and climate-smart agricultural practices under diverse agro-ecological conditions (8). Despite this growth, the literature remains fragmented, with studies differing in regional focus, methodological approaches and conceptual framing of perception and adoption (17). This fragmentation limits the ability to draw generalisable insights about dominant adoption strategies, perception patterns and the intellectual structure of the field.

Against this backdrop, the present study aims to identify the key adoption strategies and perception levels of climate change in global agriculture through an integrated systematic review and bibliometric analysis. Specifically, the study examines publication trends, keyword co-occurrence, co-authorship networks, major publication sources and bibliometric coupling to identify the intellectual structure of climate change adoption research (18–20). The findings are expected to support future research, policy formulation and climate-resilient agricultural development.

Methodology

This study adopts a structured bibliometric and systematic review methodology to examine trends and patterns in climate change research. A systematic literature search was conducted using the Scopus database, covering the publication period from 2015 to 2025. The search strategy employed carefully selected keywords related to climate change perception, adaptation practices, climate-smart agriculture, farmer behaviour and agricultural resilience. The detailed search strings, search fields and database filters applied during the retrieval process are presented in Table 1.

The retrieved publications were analysed using bibliometric techniques to assess annual scientific production, the co-occurrence of author keywords, co-authorship networks, leading publication sources and document coupling patterns. These analyses were performed using RStudio (Bibliometric package) and VOSviewer, which are widely recognised tools for bibliometric visualisation and network analysis.

In addition to bibliometric analysis, a systematic literature review was undertaken following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines to ensure transparency and methodological rigour. Clear inclusion and exclusion criteria were established prior to screening and are detailed in Table 2.

Using the predefined search strategy, a total of 981 records were initially retrieved from the Scopus database by searching within the title, abstract and keywords fields. This approach was adopted because these fields contain the most relevant and concise representation of a study's core content, thereby

Table 1. Search strategy and database filters applied in the Scopus search

Data bases	Search strings	Filters applied	Total no. of articles
Scopus	("climate change" OR "weather change" OR "climate variation") AND ("perception" OR "perceptive") AND ("adoption" OR "adoption strategies")	Time span: 2015–2025; document type: article and review; language: English; source type: journal; publication stage: final; subject area: environmental science, social science, agricultural and biological sciences; access type: open access	981

Table 2. Inclusion and exclusion criteria used in the preferred reporting items for systematic reviews and meta-analyses (PRISMA) screening process

Criteria	Inclusion	Exclusion
Time span	2015–2025	<2015
Document type	Article, review	Conference papers, Book chapters, Editorial
Languages	English	Non-English
Source type	Journal	Conference proceeding, Book series, Book
Publication stage	Final	Article in press
Keywords	Adoption; adoption behaviour; adaptive management; agricultural development; agricultural extension; agricultural practice; agricultural production; agricultural technology; behaviour; biodiversity; climate; climate adaptation; climate change; climate change adaptation; climate change perception; climate variability and change; climate variation; climate-smart agriculture; cropping system; decision making; environmental risk; farmer perception; farmers; farmers' knowledge; farming system; food security; global warming; mitigation; nature-based solutions; perception; perceptions; risk perception; rural area; smallholder farmers; subsistence farming; sustainable agriculture; sustainable development goals; surveys; zero hunger	All other keywords
Open access	All open access	Restricted access
Subject area	Environment science, social science, agricultural and biological sciences, psychology	All other subjects
Screening		
Title and abstract	Studies were selected based on whether the titles and abstracts contained the predetermined key terms relevant to the research	
Full text	Only articles that addressed the identified key terms within their full text were considered eligible for inclusion in the study	

improving the precision and relevance of the retrieved results while minimising the inclusion of unrelated records. During the screening stage, 654 records were excluded based on the inclusion and exclusion criteria mentioned in Table 2. The remaining 327 publications were retained after applying automated database filters using Scopus to enhance the relevant study. A further refinement was undertaken through a detailed screening of titles, abstracts and author-provided keywords to ensure the inclusion of studies that are both highly relevant and methodologically sound. This process enhanced the rigour, reliability and thematic coherence of the dataset by systematically excluding irrelevant and low-quality records. Consequently, a final set of 117 publications was retained, which constituted the dataset for both the bibliometric analysis and systematic review, as illustrated in the PRISMA flow diagram (Fig. 1). The combined use of PRISMA guidelines, RStudio and VOSviewer strengthened the reliability and reproducibility of the review process.

Results

Annual scientific production

A bibliometric analysis of Scopus database was conducted using RStudio. In the initial years, publications were very limited, suggesting that the topic initially occupied a niche position within agricultural research (Fig. 2). A gradual increase over the following period suggests rising awareness among scholars about the need to understand how farmers perceive climatic risks and translate

that perception into adaptive action. The brief fluctuation observed before 2020 reflects a transition phase in which foundational concepts and methods were being established.

From 2020 onwards, publication output rises sharply, signalling a shift from exploratory studies to a more structured and theory-driven research agenda. This growth is likely associated with intensified global policy dialogues on climate resilience and sustainable food systems, which created demand for evidence-based adoption strategies. The sustained high output in the most recent years indicates that the field has matured into an active and collaborative research domain. Overall, the pattern confirms that climate change perception is increasingly recognised as a critical driver of adoption strategies and bibliometric evidence points to a rapidly consolidating and intellectually interconnected body of literature.

Co-occurrence network - author keyword

The keyword co-occurrence network presented in Fig. 3 reveals the multidisciplinary structure of climate change adaptation research in agriculture. The analysis was performed using VOSviewer based on author keywords extracted from the selected Scopus-indexed publications. A minimum occurrence threshold of 57 was applied to identify the most frequently recurring and strongly connected keywords within the dataset. Network visualisation and clustering were generated using the VOSviewer association-strength normalisation method, which groups closely related keywords into thematic clusters based on co-occurrence intensity. The central position of “climate change” demonstrates

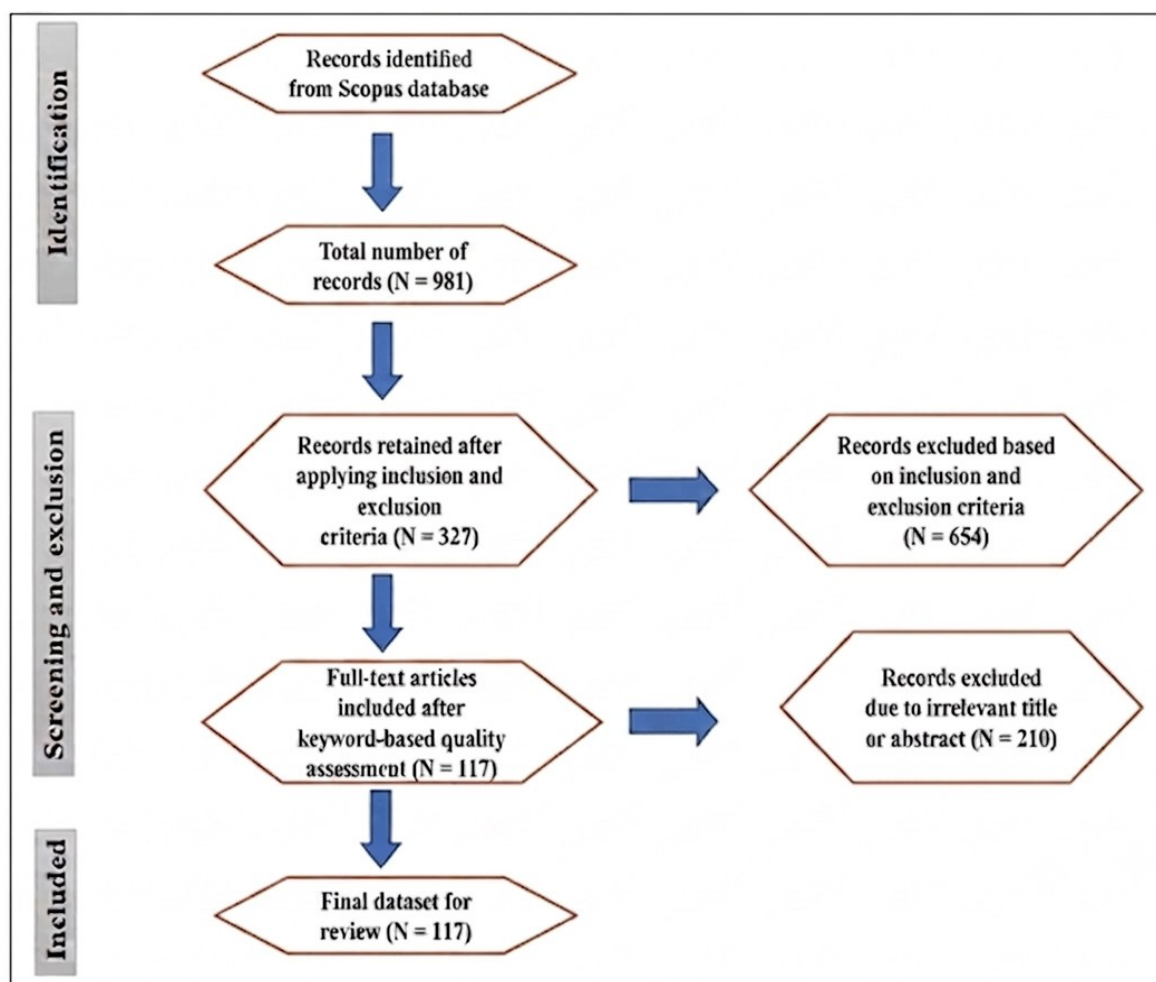


Fig. 1. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram showing identification, screening, eligibility and final inclusion of studies from the Scopus database.

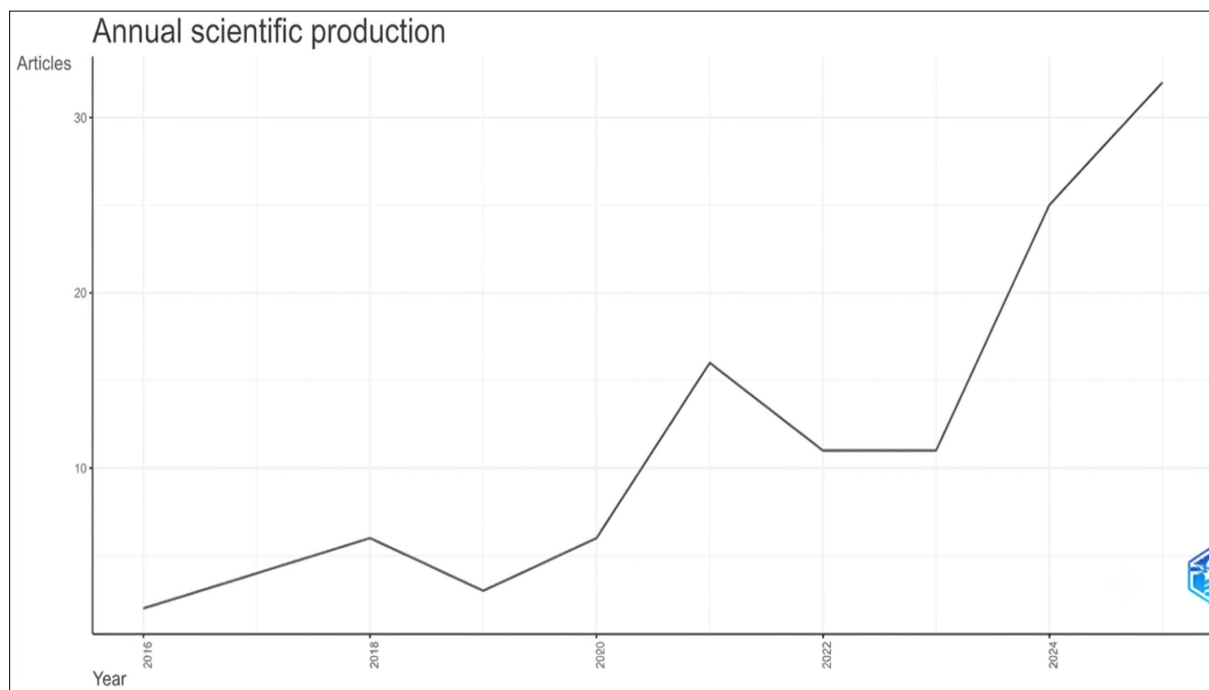


Fig. 2. Annual scientific production of Scopus-indexed publications (2015–2025), generated using the Bibliometrix package in RStudio.

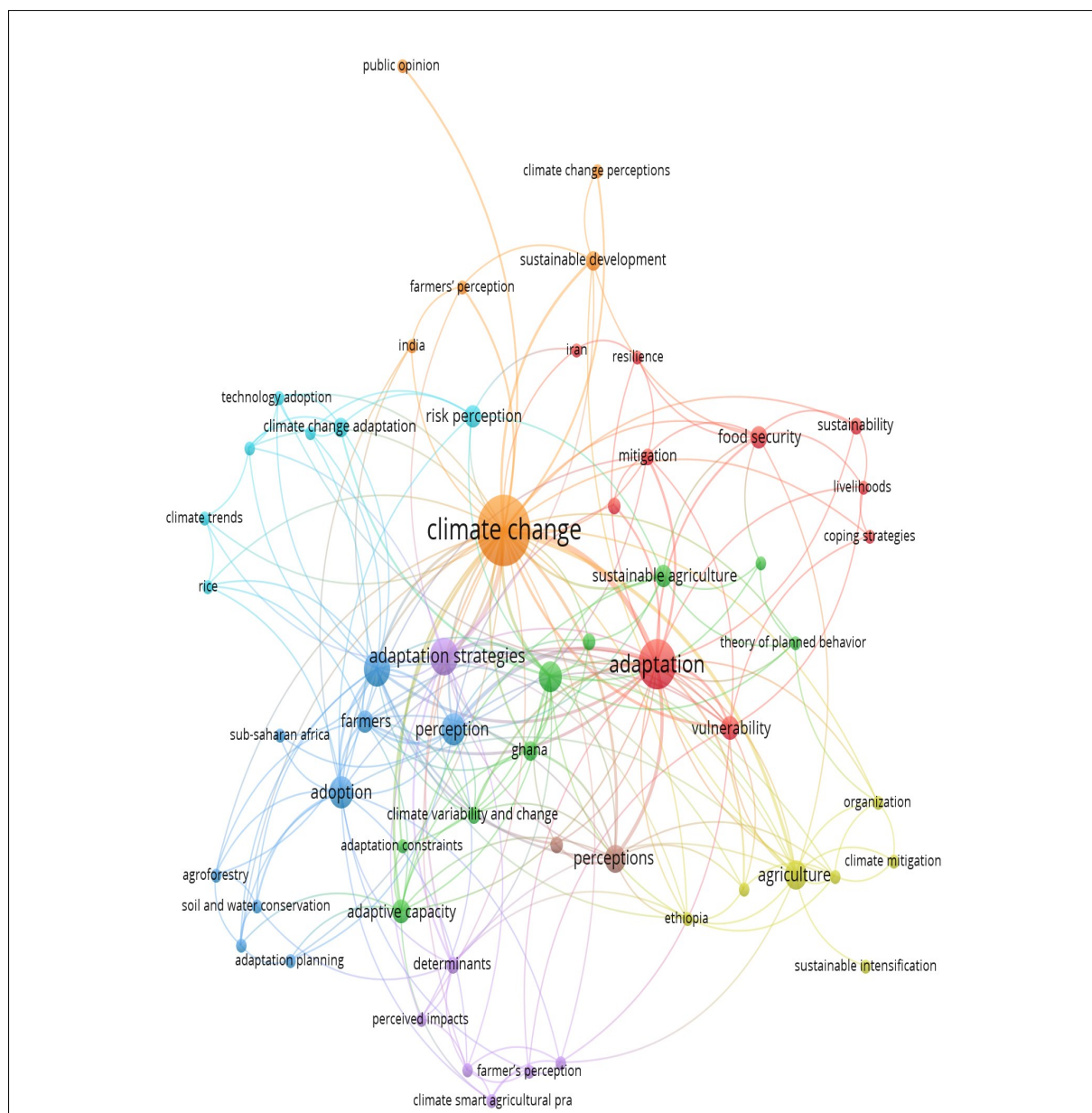


Fig. 3. Author keyword co-occurrence network generated using VOSviewer from Scopus-indexed publications.

its role as the primary integrating concept linking major research themes. Strong connections among “perception”, “risk perception”, “farmers” and “adaptation” indicate that behavioural understanding and experiential climate awareness remain central to adaptation research.

Distinct thematic clusters further highlight the intellectual organisation of the field. One cluster emphasises adaptive capacity and adaptation practices, while another links food security, livelihoods and sustainability, reflecting welfare-oriented and resilience-based perspectives. The presence of terms such as “sustainable agriculture”, “climate-smart agriculture” and “technology adoption” reflects an applied orientation towards innovation-led solutions. Regional keywords like India, Ghana and Sub-Saharan Africa demonstrate strong contributions from climate-vulnerable regions, reinforcing the global and context specific nature of adoption research.

Co-authorship of authors network analysis

The co-authorship network reveals that research on climate change perception and agricultural adoption is organised around a few strongly connected collaborative groups. Fig. 4 illustrates the presence of two dense clusters, indicating that scholars tend to work within established research teams that repeatedly publish together, allowing them to build specialised and cumulative expertise. Within each cluster, the high number of internal linkages reflects frequent joint authorship, suggesting trust, shared datasets and long-term research partnerships.

A key bridging author positioned between the two clusters plays an important integrative role by linking otherwise separate collaboration groups. This connector likely facilitates knowledge exchange, methodological diffusion and cross-regional comparison of adoption practices. The structure implies that, while collaboration is strong, it is somewhat regionally or institutionally concentrated rather than fully globalised. Such semi-clustered collaboration patterns are common in emerging

interdisciplinary fields where networks initially grow around influential research leaders.

The visible ties between the clusters nevertheless indicate increasing openness and interaction across groups. This evolving connectivity supports the formation of a more cohesive research community, which is essential for synthesising diverse farmer perception studies and developing broadly applicable adoption frameworks in global agriculture.

Most relevant source

The distribution of publications across sources indicates that research on climate change perception and agricultural adoption is concentrated in a small group of high-impact, interdisciplinary journals. Fig. 5 represents the leading position of *Sustainability* reflects the broad framing of adoption as part of long-term environmental and socio-economic sustainability, attracting studies that link farmer behaviour with resilient food systems. The strong contribution of *Climate Services* highlights the growing importance of climate information, advisories and decision-support tools in shaping farmers’ perception and response to climatic risks.

Journals such as *Agriculture*, *Climatic Change* and *GeoJournal* show that the topic is addressed from both biophysical and socio-spatial perspectives, indicating integration of agronomic evidence with human and regional analysis. The presence of outlets focused on management of natural resources, including water and farming systems, suggests that adoption strategies are often examined through practical resource-use efficiency and system redesign. Mid-level contributors like *Discover Sustainability* and the *International Journal of Climate Change Strategies and Management* point to increasing managerial and policy-oriented discussions. Overall, the spread across sustainability, climate science and applied agricultural journals confirms that the field is inherently interdisciplinary and oriented toward actionable, real-world adoption solutions.

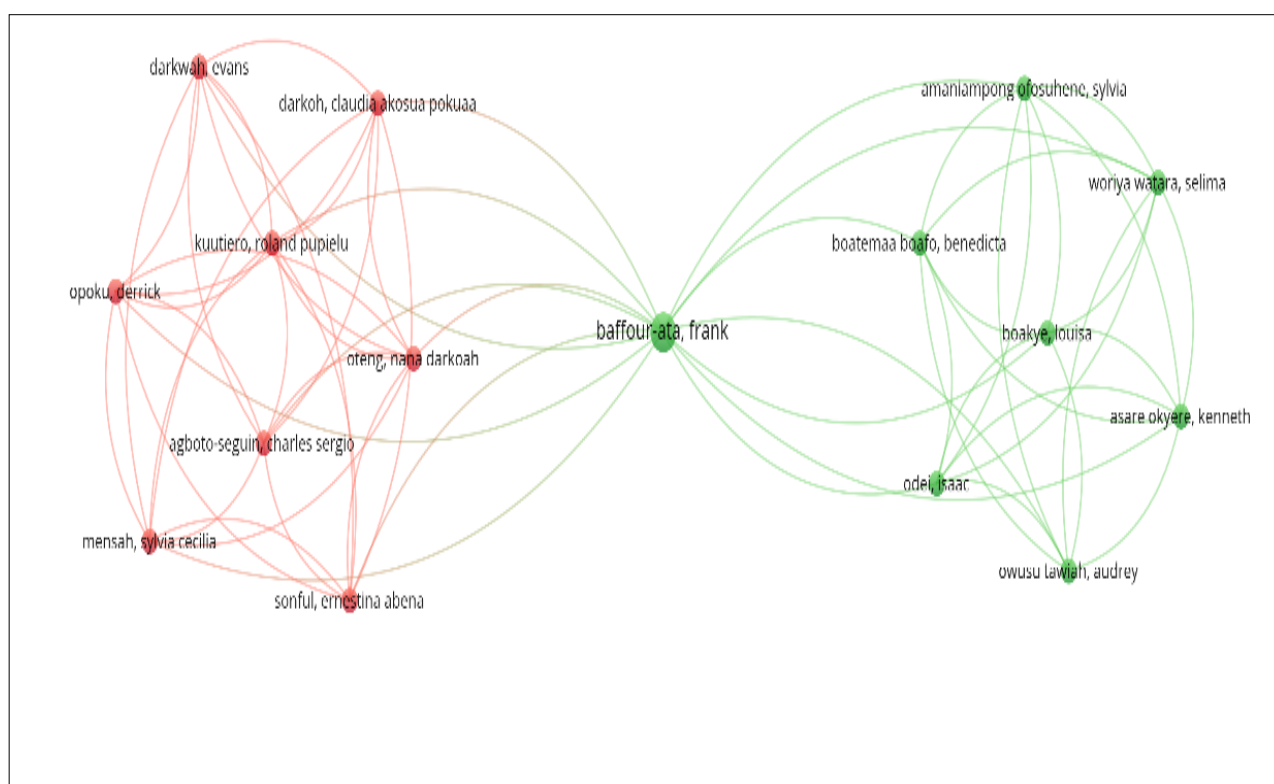
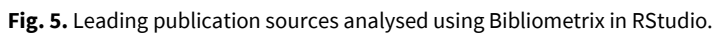
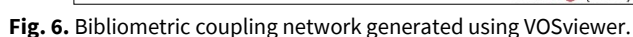


Fig. 4. The co-authorship of authors network analysis generated using VOSviewer.



The bibliometric coupling map highlights the intellectual backbone of research on climate change perception and adaptive strategies in agriculture. Fig. 6 represents larger nodes represent documents that share many common references with others, indicating that they have strongly shaped subsequent studies. The prominence of a few central papers suggests the emergence of core conceptual and methodological foundations that many recent works build upon. Dense linkages among these key documents show that the field is not fragmented but connected through shared theoretical frameworks and empirical evidence.

blue cluster emphasises farmer perception, behavioural responses and climate-risk awareness. The red cluster is associated with agricultural adaptation practices and socio-economic determinants influencing adoption behaviour. The yellow cluster highlights climate-smart agriculture, institutional support and sustainability-oriented approaches, whereas the purple cluster reflects studies related to policy, governance and climate information systems. Smaller interconnected clusters further indicate emerging interdisciplinary themes linking perception, resilience and adaptation planning. The interconnections between clusters demonstrate that newer publications increasingly integrate behavioural insights with biophysical and socio-economic analysis. This pattern reflects a maturing research domain where adoption is understood as a multidimensional process linking perception, capacity and action.



Perception level

The perception profile derived from the 117 Scopus-indexed studies included in the review are depicted in Fig. 7. The reported percentages were obtained through percentage analysis by grouping similar climate perception themes repeatedly identified across the selected studies. Thus, the values represent aggregated thematic frequencies from the reviewed literature and not weighted estimates from primary field surveys. The findings, when interpreted alongside the bibliometric results, reveal a strong alignment between research trends and farmers' experiential understanding of climate change. The rapid increase in scientific publications after 2020 reflects growing global attention toward climate risks that are directly observable at the farm level. This is clearly mirrored in the perception data, where farmers most strongly associate climate change with temperature rise and heat stress (20 %). The dominance of temperature-related perception corresponds with the increasing research focus on heat stress impacts highlighted in recent literature, as rising temperatures directly affect crop growth duration, evapotranspiration rates, soil moisture depletion and labour conditions in agricultural systems (17).

Similarly, the keyword co-occurrence network shows strong linkages between “climate change”, “perception”, “risk perception” and “adoption”, indicating that farmer perception is a central theme in the research landscape. This is reflected in the perception results, where rainfall variability and erratic monsoon behaviour account for 18 %, demonstrating that uncertainty in rainfall patterns is a critical driver of both research attention and farmer decision-making processes (16).

The regional distribution of studies, particularly the strong representation of climate-vulnerable regions such as India, Sub-Saharan Africa and Southeast Asia, helps explain why drought and water scarcity (16 %) and extreme climate events (15 %) emerge as major perception components. In these regions, frequent exposure to droughts, floods and climatic shocks intensifies farmers' awareness and shapes their perception toward immediate and livelihood-threatening risks (7).

Furthermore, the thematic clustering identified through bibliometric coupling, which links perception with vulnerability,

livelihoods and resilience, is directly reflected in farmers' recognition of pest and disease incidence (12 %) and declining crop productivity (11 %). These perceptions capture the cumulative biological and economic impacts of climate stress on agricultural systems and reinforce the strong integration of social and biophysical dimensions in the research field (5, 8).

Despite the growing scientific focus on climate change, only 8 % of farmers associate it with broader environmental processes and long-term risks, indicating that perception remains largely grounded in immediate, experience-based impacts rather than abstract scientific understanding. These perception patterns act as a critical link between scientific knowledge production and real-world agricultural adaptation, ultimately influencing the adoption of climate-resilient strategies in global agriculture (11).

Adoption strategy

Crop diversification and cropping system adjustment

Crop diversification and cropping system adjustments emerge as widely adopted responses to climate variability, driven by farmers' perceptions of rainfall uncertainty, temperature stress, droughts, floods and pest pressures. The growing emphasis on these practices corresponds with the sharp rise in scientific publications after 2020, indicating increased research focus on practical, farm-level responses to climate risk.

Empirical evidence from Sub-Saharan Africa consistently highlights diversification as a key risk-management strategy (21). Similarly, among smallholder farmers in Ethiopia, intercropping, crop rotation and mixed cropping were widely practiced to buffer climate-induced yield instability and enhance system resilience (22–24). In Benin and Senegal, diversification was identified as a core climate-smart agriculture (CSA) practice aimed at stabilising household food security under increasing climatic stress (25–27).

In South Asia, particularly India, Bangladesh, Pakistan and Nepal, crop diversification and cropping system adjustments were closely linked to farmers' perceptions of delayed monsoons, rising drought frequency, salinity intrusion and flooding. Studies from Eastern India reveal that farmers diversified crops, adopted mixed cropping and rescheduled planting dates as adaptive responses to

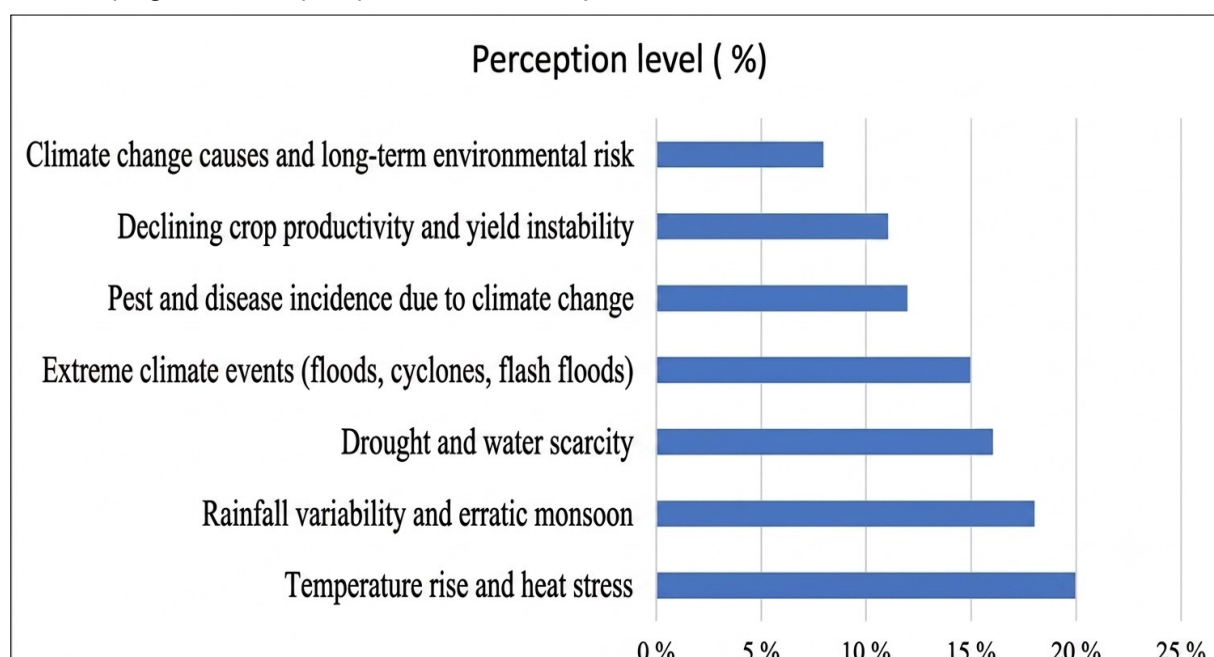


Fig. 7. Farmers climate change perception profile derived from reviewed Scopus-indexed studies.

monsoon variability and temperature rise (28, 29). In flood- and salinity-prone coastal regions of Bangladesh, farmers adjusted cropping patterns, shifted crop types and increasingly adopted short-duration varieties to cope with recurrent climate shocks (30–33). Similarly, in Pakistan, diversification and mixed cropping were widely reported as coping strategies against rainfall uncertainty, pest outbreaks and declining water availability, although adoption intensity remained constrained by resource limitations in some regions (34–36).

Global syntheses further confirm that diversification and shifts toward less climate-sensitive crops are among the most commonly practiced responses across developing regions, primarily due to their low cost, flexibility and compatibility with existing farming systems (37, 38). Evidence from Latin America and other regions also indicates that diversification supports livelihood security and improves system efficiency under climate stress (39–43).

Adoption of climate-resilient and improved crop varieties

The adoption of climate-resilient and improved crop varieties has emerged as one of the most widely reported adoption strategies in agriculture, particularly in regions experiencing increased climatic variability, frequent droughts, floods and temperature extremes. These varieties, characterised by early maturity, drought tolerance, flood tolerance, disease resistance and higher yield potential enable farmers to stabilise production under uncertain climatic conditions.

The growing emphasis on such varieties aligns with the expansion of research output in recent years and the strong bibliometric linkage between perception, risk and technological response. Evidence from Sub-Saharan Africa indicates that farmers adopt early maturing and drought-tolerant varieties to cope with erratic rainfall and shortened growing seasons, although adoption remains uneven where institutional support and seed access are limited (21, 25, 37, 39, 44).

In South Asia, the adoption of climate-resilient crop varieties has been closely linked to farmers' socio-economic characteristics and exposure to climate risks. In Bihar, India, the uptake of stress-tolerant and improved varieties was significantly influenced by education level and farm size, suggesting that resource-endowed farmers are better positioned to adopt technological innovations (28). In eastern India, particularly Odisha, only a small proportion of farmers adopted drought-resistant and early maturing varieties, reflecting constraints related to awareness and seed accessibility (29). Conversely, systematic evidence across India indicates widespread adoption of stress-tolerant and improved varieties, especially in regions facing recurrent droughts and floods (38).

In climate-vulnerable regions such as coastal Bangladesh, farmers increasingly prefer short-duration and resilient varieties to reduce crop loss from extreme events (30–33, 45). Evidence from East and Southern Africa further supports the role of improved varieties as a climate adoption pathway, although adoption intensity was often constrained by high seed costs and limited market access (22, 46, 47). Systematic reviews confirm that climate-resilient varieties are among the most consistently adopted adoption strategies globally, often combined with other climate-smart practices to enhance farm resilience (38, 41, 48, 49).

Water management and irrigation adoption strategies

Water management and irrigation practices represent a critical response to increasing climate variability, particularly under conditions of rainfall uncertainty, drought and declining water availability. Farmers adopt a combination of irrigation expansion, soil moisture conservation, rainwater harvesting and efficient water-use technologies to stabilise production and reduce climate-induced risks.

The keyword co-occurrence patterns, which highlight strong associations between climate risk, water scarcity and adaptive decision-making, are reflected in farmers' reliance on irrigation expansion, soil moisture conservation, rainwater harvesting and efficient water-use technologies to stabilise production. Across Sub-Saharan Africa, water-related practices are primarily shaped by exposure to erratic rainfall and moisture stress, with farmers relying on conservation techniques and rainfed water management approaches to sustain crop production (21, 22, 24, 50). However, limited infrastructure, financial constraints and weak institutional support continue to restrict the expansion of irrigation systems in many regions (25, 51).

In South Asia, water-use practices closely align with farmers' perceptions of monsoon variability and declining water availability, leading to increasing uptake of irrigation and micro-irrigation technologies, although diffusion remains uneven due to governance and resource limitations (28, 29, 34, 36, 38). In climate-sensitive environments such as coastal Bangladesh, drainage management and regulated irrigation are prioritised to address flooding and salinity risks (30, 32, 33, 45).

Bibliometric coupling further reveals strong thematic linkages between water management, resilience and sustainability, which are reflected in the adoption of advanced irrigation technologies and climate-informed planning in developed regions (46, 47). In contrast, studies from the USA, Europe and Australia highlight the adoption of smart irrigation technologies, managed aquifer recharge, regulated deficit irrigation and climate-informed water planning, reflecting higher adaptive capacity and access to technology (43, 52–54).

Global syntheses confirm that water management forms a foundational component of climate-smart agriculture, often combined with soil and crop management practices to enhance overall system resilience (37). Overall, adoption of water management strategies is strongly mediated by access to infrastructure, financial resources, governance systems and climate information, with persistent socio-economic and institutional barriers limiting uptake among smallholder farmers.

Soil and land management practices as climate change adoption strategies

Soil and land management practices represent a fundamental response to climate-induced changes in soil fertility, moisture availability and land productivity. The increasing emphasis on these practices aligns with bibliometric trends, which highlight strong thematic linkages between climate risk, resource degradation and sustainable land-use management.

Across Sub-Saharan Africa, soil-related practices are primarily driven by declining fertility and increasing land degradation under variable climatic conditions. Farmers adopt measures such as composting, residue management, agroforestry and integrated soil

fertility approaches to enhance soil structure and moisture retention (21–23, 50). However, adoption remains constrained in many regions due to financial and resource limitations (25, 35).

In South Asia, soil management practices are closely associated with farmers' perceptions of fertility decline, rising input requirements and land degradation. Farmers increasingly adopt crop rotation, soil conservation techniques and nutrient management practices to sustain productivity under changing climatic conditions (28, 29). In coastal Bangladesh, land-based practices such as tree plantation and soil management are used to address salinity intrusion and erosion challenges, although effectiveness is often limited in highly degraded soils (30, 31).

Bibliometric evidence further indicates that conservation-oriented soil practices are strongly linked with resilience and sustainability themes, particularly in regions with greater institutional support, where practices such as reduced tillage and erosion control are more widely implemented (41, 43, 55). Overall, the adoption of soil and land management practices is shaped by resource availability, knowledge systems and institutional support, with persistent constraints limiting wider uptake (37).

Adjustment of farm management practices as climate change adoption strategies

Adjustment of farm management practices represents one of the most immediate and flexible responses to climate variability in agriculture. The growing volume of publications identified in the bibliometric analysis highlights increasing research attention toward behavioural adaptation, climate risk perception and low-cost resilience measures across climate-vulnerable farming systems. Farmers commonly modify planting and harvesting schedules, input allocation, labour use and cropping calendars to respond to changing rainfall patterns, rising temperatures and extreme weather events.

In Sub-Saharan Africa, where a considerable share of studies is concentrated, farm-level adjustments are primarily shaped by rainfall uncertainty and shortened growing seasons. Farmers increasingly alter planting dates, row spacing and agronomic operations to synchronise crop growth with shifting climatic conditions (21, 22, 24–26). Similarly, keyword co-occurrence analysis linking “climate change”, “perception” and “adaptation” is reflected in South Asia, where management adjustments are closely associated with monsoon variability and heat stress, leading farmers to revise sowing periods and cropping calendars to minimise production risks. In Bihar, India, farmers adjusted sowing and harvesting dates and altered land-use decisions to cope with delayed monsoons and temperature fluctuations (28). In eastern India, particularly Odisha, sowing dates were shifted from June to July to accommodate changes in rainfall onset, highlighting calendar-based adoption as a dominant response (29). Similar patterns were observed across India, where systematic evidence indicates widespread adjustment of planting calendars, labour allocation and input use as adaptive responses to climate variability (38). In Pakistan, farmers adjusted farming operations in response to heat stress and rainfall shifts, although resource constraints limited the extent of these adoptions (34, 35).

In climate-sensitive coastal regions, early harvesting and modified cropping schedules are widely practiced to reduce losses from flooding, salinity intrusion and flash floods (31–33, 45). Bibliometric coupling further indicates strong thematic connections

between resilience, livelihood security and farm-level flexibility, reinforcing the importance of these practices as accessible and experience-based responses under resource-constrained conditions. Global evidence confirms that farm management adjustments remain widely practiced due to their flexibility and relatively low implementation cost, although their effectiveness depends heavily on climate information access and extension support (37).

Livelihood diversification and income-based strategies as climate change adoption

Livelihood diversification and income-based practices represent an important response to climate-induced livelihood uncertainty, particularly in regions where agricultural production has become increasingly vulnerable to rainfall variability, drought and declining farm returns. The growing research attention identified in the bibliometric analysis reflects increasing recognition of diversification as a resilience-oriented approach for reducing dependence on climate-sensitive farming systems.

Across Sub-Saharan Africa, diversification is frequently adopted as a risk-buffering mechanism rather than a primary livelihood transition. Farmers increasingly engage in off-farm employment, migration, savings, livestock integration and small-scale enterprises to stabilise household income under climatic stress (23, 26, 56). The thematic clustering identified through bibliometric coupling further highlights strong linkages between livelihood security, vulnerability reduction and adaptive capacity in climate-sensitive regions.

In South Asia, livelihood diversification is closely associated with climate-related income instability and production uncertainty. Farmers adopt migration, wage labour, non-farm employment and alternative income activities to offset declining agricultural returns and manage climate-related risks (28, 29, 35, 36). In highly climate-vulnerable coastal and flood-prone regions, livelihood diversification often reflects constrained choices rather than proactive adoption. In coastal Bangladesh, high poverty levels and land constraints limited farmers' ability to diversify livelihoods beyond agriculture, resulting in continued vulnerability despite climate stress (30, 32). Nevertheless, in some flood-prone areas, households shifted temporarily from crop cultivation to livestock rearing, fishing, homestead gardening or migration during flood periods as survival-oriented strategies (31, 33, 45).

Global evidence indicates that diversification practices become increasingly important where farming alone is insufficient to sustain livelihoods, although access to assets, education, labour mobility and institutional support strongly influence households' capacity to diversify effectively (37, 38).

Institutional and information-based strategies as climate change adoption

Institutional and information-based practices play a central role in shaping farmers' climate perceptions and their capacity to respond effectively to climatic risks. The growing volume of publications and thematic linkages identified in the bibliometric analysis highlights increasing research attention toward extension support, climate information systems, governance and institutional resilience as key determinants of adaptive capacity.

Across Sub-Saharan Africa, access to extension services, climate advisories, training programmes and information and communications technology (ICT)-based communication platforms

significantly influences farmers' responses to rainfall variability and production uncertainty (21–23, 50). At the same time, inadequate institutional coordination, weak communication networks and limited technical support continue to constrain wider uptake of climate-responsive practices in several regions (34, 47).

In South Asia, institutional support mechanisms such as extension services, subsidies, farmer training and access to credit strongly shape adaptive decision-making under increasing climate variability (28, 29, 57). However, gaps in timely weather information, limited outreach and uneven policy implementation remain major barriers in highly climate-exposed farming systems (33, 35). In climate-sensitive coastal and wetland environments, community organisations, water management institutions and early-warning systems play a particularly important role in strengthening preparedness and reducing climate-related losses (30–32, 46).

Bibliometric coupling further demonstrates strong thematic connections between governance, climate communication and resilience-building, reinforcing the importance of institutional trust and information accessibility in enabling effective climate responses among smallholder farmers (37).

Climate change perception as a determinant of adoption in agriculture

Farmers' perception of climate change is widely recognised as a key factor influencing agricultural responses to climatic stress. The bibliometric analysis highlights a substantial rise in publications focusing on perception, vulnerability and adaptive behaviour, indicating growing research attention toward the role of farmer awareness in shaping climate-responsive decision-making.

Studies from Sub-Saharan Africa reveal strong and widespread recognition of climate change and its impacts on agriculture. In Ghana's Upper East Region, farmers perceived rising temperatures, erratic rainfall and frequent droughts as serious threats to food production, which strongly motivated adaptive behaviour (21). Similar findings were reported in Ethiopia, where the majority of farmers perceived increasing temperature and declining rainfall over the past decades, with perception acting as a positive determinant of CSA adoption (50, 58, 59). Evidence from Benin, Senegal and Rwanda further indicates that more than 80 % of farmers clearly perceive climate variability and extremes and these perceptions are closely linked to the adoption of soil, water and crop management strategies (60, 61). These findings correspond with the keyword co-occurrence patterns identified in the bibliometric results, where "perception", "adaptation" and "risk" emerge as closely interconnected themes.

In South Asia, high exposure to monsoon variability, floods, droughts and heat stress has intensified farmers' experiential understanding of climate change, encouraging greater willingness to modify farming operations and livelihood practices (62–65). Similarly, in climate-sensitive coastal and wetland environments, repeated exposure to flooding, salinity intrusion, cyclones and unpredictable weather has strengthened risk awareness and influenced adaptive behaviour among farming households (66–74).

Bibliometric coupling further reveals strong thematic linkages between climate perception, resilience and institutional support, reinforcing that perception acts as a cognitive trigger for adaptation, although effective responses remain dependent on access to resources, extension services and reliable climate information (75–78).

Discussion

Bibliometric analysis

The bibliometric findings indicate that research on climate change adaptation in agriculture has transitioned from a fragmented research area into a more integrated and policy-relevant knowledge domain. The sharp increase in publications after 2020 reflects not only growing scientific interest but also the influence of global climate policies, food security concerns and the increasing recognition of farmers as central actors in adaptation processes. The dominance of keywords related to "perception", "adaptation" and "climate-smart agriculture" suggests that recent research increasingly acknowledges behavioural and socio-economic dimensions rather than relying solely on technological interventions.

The thematic clustering further demonstrates a gradual shift from isolated agronomic studies toward interdisciplinary approaches linking vulnerability, resilience, livelihoods and institutional support. This evolution highlights the growing understanding that adaptation outcomes are shaped by both environmental exposure and socio-economic capacity. In addition, the strong bibliometric coupling among studies indicates the emergence of shared conceptual frameworks connecting climate perception with farm-level decision-making. However, despite expanding global research output, significant geographical and institutional disparities remain evident, with comparatively limited representation of highly vulnerable smallholder systems in low-income regions. These gaps suggest the need for more context-specific, locally grounded and interdisciplinary research capable of addressing diverse adaptation realities across agricultural systems.

Climate change perception

The findings suggest that farmers' perception of climate change is largely shaped by continuous exposure to visible climatic disturbances such as temperature rise, irregular rainfall, droughts and floods, which directly threaten agricultural productivity and household livelihoods (7, 17). This experience-driven understanding strengthens farmers' awareness of climate risks and encourages practical responses that are more closely aligned with local farming realities than abstract scientific interpretations (8). The high perception levels observed in climate-sensitive regions further indicate that repeated exposure to extreme events accelerates risk recognition and adaptive thinking among farming communities (5). Nevertheless, perception alone is insufficient to ensure effective response measures, as the translation of awareness into action depends heavily on access to institutional support, reliable climate information, financial resources and extension services (11).

Adoption strategies

The synthesis of evidence indicates that farmers generally prefer responses that are practical, economically feasible and compatible with existing farming systems rather than highly capital-intensive interventions (21). Crop diversification and modifications in cropping patterns are widely practiced because they distribute climatic risk across multiple crops and growing periods, thereby improving production stability under uncertain rainfall and temperature conditions. Similarly, climate-resilient crop varieties are increasingly valued for their ability to maintain yield performance under drought, flooding and heat stress, particularly where extension services and seed distribution systems are effective (44).

Water and soil management practices emerge as critical long-term resilience measures because they protect soil fertility, improve moisture retention and reduce degradation risks that intensify under climate stress (55). Farm-level operational adjustments, including changes in sowing schedules and agronomic practices, are frequently adopted due to their flexibility and relatively low implementation cost (45). Livelihood diversification further strengthens household resilience by reducing dependence on climate-sensitive agricultural income, although unequal access to assets and employment opportunities often limits diversification capacity among smallholders (56). The findings also demonstrate that institutional support, climate information and extension services play a decisive role in shaping the success of adaptation responses by enhancing farmers' confidence, knowledge and decision-making capacity (57).

Conclusion and future directions

This review demonstrates that climate change adoption in global agriculture is fundamentally shaped by farmers' perception of climatic stress, which acts as the primary cognitive trigger for adoption decisions. The bibliometric analysis confirms a rapid expansion and consolidation of research in this domain, with dominant themes linking climate perception, adaptive capacity, food security and climate-smart practices, indicating a shift toward farmer-centred and interdisciplinary adoption frameworks. Evidence from the systematic review shows that farmers consistently favour flexible and experience-based strategies such as crop diversification, climate-resilient varieties, water and soil management and farm management adjustments because these directly mitigate risks associated with rising temperatures, rainfall variability, droughts and extreme events. However, the translation of perception into sustained adoption remains uneven, largely constrained by disparities in access to extension services, climate information, financial resources and institutional support. These findings highlight that effective adoption is not only a technical challenge but also an institutional and behavioural one. Future research should prioritise longitudinal and comparative studies to capture dynamic changes in perception and adoption over time, expand empirical coverage in under-represented and highly vulnerable regions and integrate bibliometric insights with impact-based evaluations. Strengthening linkages between research, policy and extension systems will be essential to scale context specific, inclusive and durable climate-resilient agricultural development.

Policy design and climate resilience in agricultural development

The synthesis of evidence in this review underscores that effective policy design for climate-resilient agriculture must be firmly anchored in farmers' perception of climate risk, as perception shapes both the urgency and direction of adaptive responses. Policies that prioritise farmer centred adoption through strengthened extension systems, timely climate information services and context specific advisory support are more likely to translate awareness into sustained adoption of adaptive strategies. The dominance of experience-based strategies such as crops diversification, water and soil management and farm management adjustments highlights the need for policies that support low-cost, flexible and scalable interventions, particularly for smallholder farmers. At the same time, the persistence of adoption constraints

signals that resilience cannot be achieved through technology alone; coordinated investment in institutional capacity, credit access and governance mechanisms is essential. Integrating behavioural insights from perception studies with climate-smart agricultural policies can therefore enhance the effectiveness, equity and long-term sustainability of agricultural development pathways under climate change.

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Authors' contributions

BM conceptualised the study, conducted the systematic review and bibliometric analysis, interpreted the results and drafted the manuscript. PSR provided overall supervision, guided the research design and critically reviewed and refined the manuscript. TJ contributed to data organisation, screening of literature and preliminary analysis. MM assisted in developing the analytical framework and supported interpretation of bibliometric findings. SSP contributed to manuscript editing, synthesis of results and formatting. All authors have read and approved the final manuscript.

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During the preparation of this work the authors used QuillBot solely for language support tool to assist with paraphrasing and improving the overall clarity and readability. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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