



REVIEW ARTICLE

Unveiling key adaptation strategies: A systematic review of climate variability's impact on agriculture

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Abstract

This review aims to comprehensively analyze the variability of climate in agriculture and the adaptive behaviour of farmers in response to climate change, synthesizing existing knowledge and examining measures for mitigate climate fluctuations. To achieve this, a systematic literature review (SLR) was conducted using the Scopus database, covering the past eleven years. A total of 177 articles were identified through a methodological application of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) framework. While these studies encompass a broad geographical scope, the selection was deliberately constrained by a small sample size to exclude regions lacking conflicting evidence, ensuring relevance and high-quality information, a standard practice in systematic reviews within this field. This study hypothesizes that adaptive strategies, such as climate-smart agriculture and early warning systems, significantly reduce farmers' vulnerability under climate change. Key findings indicates that practices like conservation tillage, agroforestry and other climate-resilient approaches enhances agricultural sustainability and resilience. The results highlight the urgent need for further investigation and policy incentives to encourage adaptive behaviour and provide food security in the presence of climatic variability. Thus, the conclusion of these findings encourages the widespread uptake of climate-smart practices coupled with early warning mechanisms to reduce climatic risks effectively.

Keywords

agricultural adaptation; agriculture resilience; climate change; climate variability; mitigation

Introduction

Climate variability significantly impacts agriculture by disrupting traditional practices such as cropping, livestock rearing and fish farming. In addition to these documented effects, this study seeks to understand farmer's underlying adaptive behaviours and synthesise this understanding to help reduce climate-induced vulnerabilities (1). Subsistence farmers in impoverished regions, who heavily rely on natural resources, are of particular concern as they are especially vulnerable to intensified climate extremes, including droughts, floods and heatwaves (2, 3). These challenges are exacerbated by the fact that farmers in arid climates experience up to a 30% reduction in revenue, while those in wetter conditions see a 20% decline (4). Furthermore, the unpredictability of future climate patterns, marked by significant uncertainties in climatological projections, makes planning for climate extremes exceedingly difficult (5).

Technological advancement offer promising solutions to enhance resilience, such as sustainable protein production through insect rearing on bio-waste and the techno-economic assessment of processing cellulose casings waste. These strategies demonstrate how environmental sustainability can be integrated with economic feasibility (6, 7).

This research employs a mixed-method approach, combining SLR and PRISMA framework to synthesize knowledge. The study integrates climate modelling, remote sensing technologies and economic analyses, highlighting the need importance of collaborative efforts spanning technical, ecological and socio-economic domains.

Balancing profitability with urgency is crucial to ensure longer-term sustainability in adaptation strategies. For instance, increasing methane yield from rye straw offers an economically viable method to mitigate environmental impacts while addressing immediate climatic threats (8, 9). However, economic realities, such as the prohibitively high production cost of biochar, underscore the necessity of innovative financing and resource optimization to enable large-scale adoption (10, 11).

In regions such as hilly terrains and alluvial plains, farmers generally show greater adaptability by adopting practices like cultivating short-gestating crops, using drought-resistant varieties and planting trees. Nevertheless, most smallholder farmers remain reactive, responding only to evident changes in rainfall and temperature patterns, rather than proactively developing adaptive measures to cope with the gradual shifts brought about by climate change (12).

This study aims to contribute to the field by addressing three key objectives: first, evaluating thematic research maps; second, analysing country–author collaboration networks; and finally, identifying the most influential and productive contributors in the domain of climate variability and adaptive behaviour.

Methodology

To analyse the impact of climate variability and change, the SLR method, which is a structured approach to reviewing and synthesising existing literature was used (13). This systematic review specially examined the climate change adaption strategies of Asian farmers to identify research trends and gaps in this area (14). Additionally, bibliometric analysis was conducted to provide quantitative insights into the effects of climate variability on agriculture (15).

The SLR technique facilitated the creation of detailed and comprehensive literature summaries by systematically organizing descriptions and bibliographies. The review process adhered to the PRISMA methodology, ensuring transparency and reproducibility. The literature search, conducted using the Scopus database and other sources, utilizing keyword combinations such as "climate variability," "agriculture," and "adaptation behaviour." (Table 1), which enabled a focused and targeted search strategy.

Vosviewer software was used to visualise and analyse the bibliometric data. The software allowed for the development of bibliographic connexions, thematic maps, cross-references and co-

Table 1. Combination of keywords used and the total number of publications from databases

Databases	Search terms	Numbers of
scopus	“Climate variability” AND “adaptation	520
	“Climate variability” AND “agriculture” AND “adaptation behaviour”	411

occurrence analyses, which were instrumental in identifying key trends and relationships within the literature (16). The search process, illustrated in (Fig. 1), initially identified a pool of 931 articles. As summarized in (Table 2), a 30% exclusion rate was applied based on initial relevance, narrowing the selection to 40 articles for detailed review. Using predefined inclusion and exclusion criteria, such as language restrictions, accessibility limitations and review-only articles, 545 articles were automatically filtered out. Of the remaining 386 articles, 199 were excluded, resulting in a final selection of 177 articles for quantitative analysis. These articles were chosen for their relevance, clarity and focus on stress and coping variables.

This study strengthens the evaluation of climate variability and adaptation strategies in agriculture by combining bibliometric analysis with systematic literature review methods,

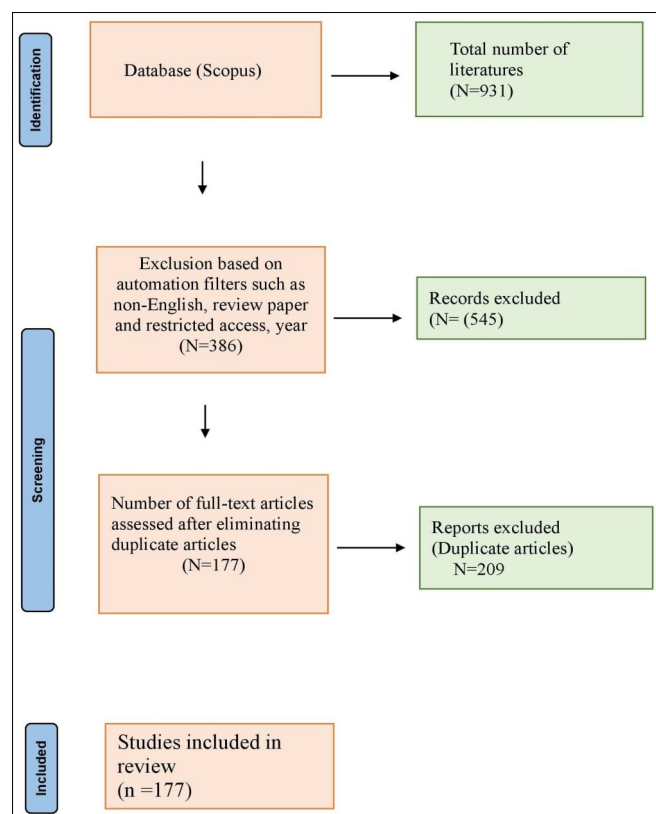


Fig. 1. PRISMA flowchart depicting the number of studies inclusion and exclusion for identifying the determinants.

offering valuable insights for researchers and policymakers.

Result and Discussion

Main information about the data (Table 3).

3.1. Data extraction

Data extraction (Table 4).

3.2. Thematic map

Thematic maps of climate variability and adaptation behavior (Fig. 2).

Table 2. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Period	2014-2024	<2014
Subject area	Social science, Agricultural & Biological Science, Multidisciplinary, Environmental science	Earth and planetary science, Engineering, Economics, Econometrics and Finance Biochemistry, Genetics and Molecular Biology, Energy, Medicine, Arts and Humanities, Computer Science, Business, Management and Accounting, Decision Sciences, Immunology and Microbiology, Chemical Engineering, Veterinary, Mathematics, Chemistry, Psychology, Physics and Astronomy, Materials Science, Neuroscience, Pharmacology, Toxicology and Pharmaceutics, Health Professions, Nursing Conference papers, Book chapters
Document Type	Article	Non-English
Languages	English	Trade journal
Source type	Journal	Press
Publication stage	Final	Restricted access
Open access	Open access	
Screening		
Title and abstract	Existence of predefined keywords in the title, abstract, or keywords part of the paper. Considered the climate variability and adaptation behaviour as an outcome.	
Full text	Included at least two determinants from climate variability, agriculture, and adaptation behaviour.	

Table 3. Main information about the data

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2014:2024
Sources (Journals, Books, etc)	103
Documents	177
Annual Growth Rate %	15.82
Document Average Age	2.87
Average citations per doc	15.98
References	13307
DOCUMENT CONTENTS	
Keywords Plus (ID)	844
Author's Keywords (DE)	600
AUTHORS	
Authors	842
Authors of single-authored docs	14
AUTHORS COLLABORATION	
Single-authored docs	14
Co-Authors per Doc	5.27
International co-authorships %	41.81
DOCUMENT TYPES	
article	177

Table 4. Data extraction

S.no.	Author	Year	Research findings	Research gap
1.	(18)	2014	Farmers used various adaptation strategies to mitigate climate variability, especially irrigation was considered the most essential strategy.	Understanding how cultural norms and traditional knowledge influence farmers' decision-making on adaptation behaviour.
2.	(19)	2015	Adapted traditional farming practices to mitigate climate change and variability.	It is important to assess how social networks impact the adaptation of traditional farming practices.
3.	(20)	2016	Based on their perceptions of climate variability, farmers can make investment decisions according to the assistance of indigenous knowledge.	Climate resilience would cause a reduction in farmers' income.
4.	(21)	2017	The adoption of sustainable agricultural practices is used to reduce climate variability issues.	The socio-economic conditions of farmers play a vital role in their adaptation behavior.
5.	(22)	2018	The adaption behavior was significantly influenced by education and innovativeness; therefore, it is necessary to educate farmers on the significance of climate change adaptation.	A crucial aspect of overcoming climate variability is climate-smart agriculture.
6.	(23)	2019	Climate variability leads to a decrease in the length of crop growing season and chemical fertilizers were used to overcome this barrier.	The usage of organic fertilizers would neglect environmental vulnerability.
7.	(24)	2020	Farmers' adoption of climatic variability adaptation measures was highly influenced by age, gender, education level, and agricultural experience.	Adaption funds have the potential to accelerate the execution of adaption strategies and aid marginalized populations in enhancing their ability to withstand the fluctuations of climate.
8.	(25)	2021	The most prevalent ways to mitigate the short-term effects of climate variability were to alter growing seasons (sowing and harvesting), as well as to apply fertilizers and pesticides.	To improve adaptive capacity and lessen vulnerability to climate variability and extremes, community-based adaptation programs and climate-resilient infrastructure are essential.
9.	(26)	2022	Based on farmer perceptions and historical weather records, preparations for climate change adaptation must be made. To enhance farming methods, skills training in climate change adaptation and mitigation could be implemented.	Access to the infrastructure, information, and resources needed to deal with climatic variability may be inhibited by socioeconomic disparities.
10.	(27)	2023	Farmers' perceptions of climate change were found to be positively correlated with their awareness of it, misinformation or the absence of accurate data may cause perceptions to become distorted.	Innovation and technological advancements, such as climate modelling, remote sensing, and renewable energy technologies, can improve the understanding of climate variability and facilitate adaptation initiatives like precision agriculture, early warning systems, and climate-resilient infrastructure.

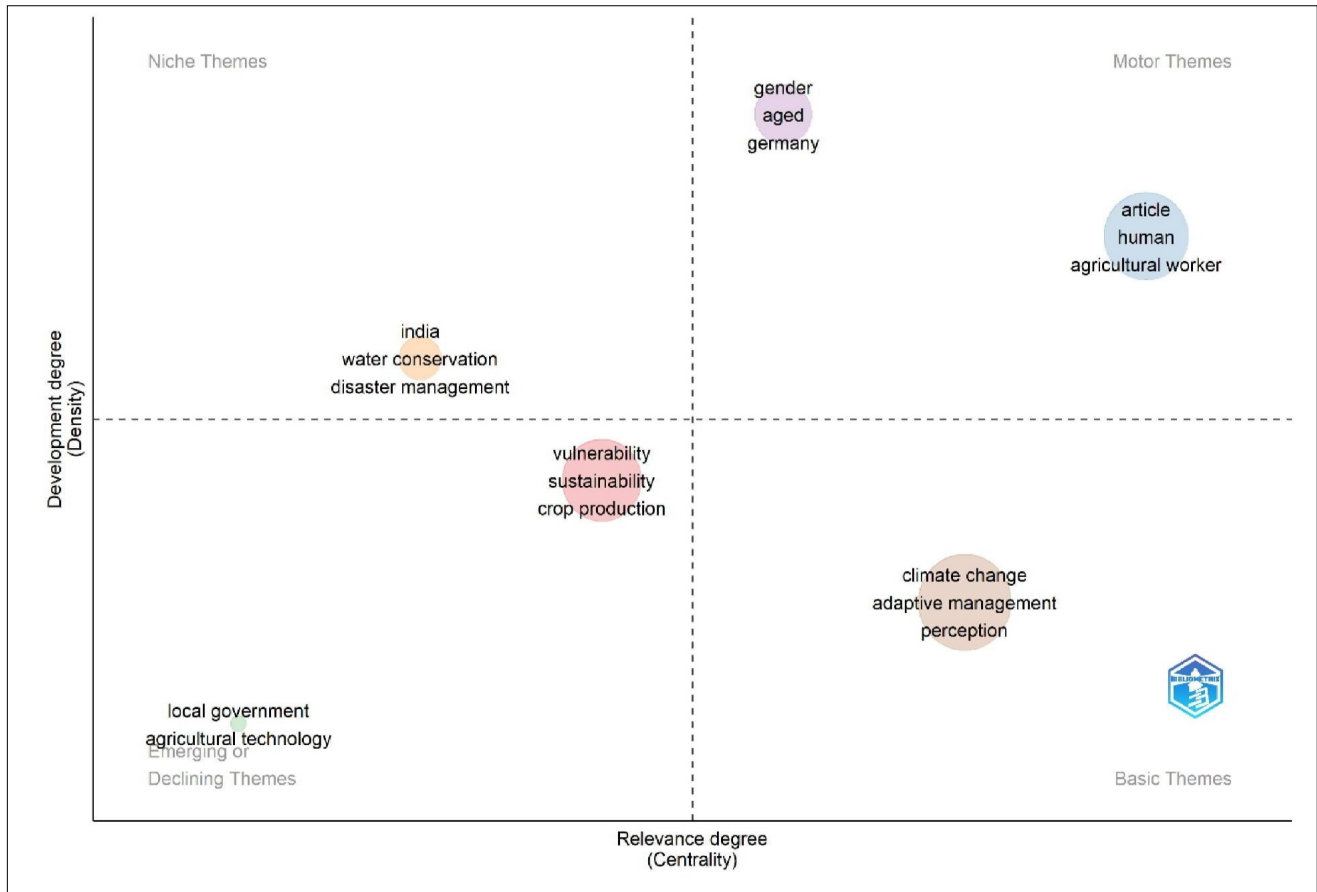


Fig. 2. Thematic maps of climate variability and adaptation behavior (Source: R studio).

This thematic map displays information on a range of vulnerability-related factors, including concepts such as "sustainability," "crop production," and "food security." These factors are grouped under the overarching theme of "vulnerability," reflecting their thematic cohesion. Betweenness centrality scores highlight the importance of specific terms in connecting various components within the cluster, with "vulnerability" emerging as a highly central term. PageRank centrality measures the overall influence of terms, while closeness centrality values indicate the proximity of each term to others within the cluster.

In terms of centrality metrics, terms such as "developing world" and "environmental policy" play a pivotal role in discussions surrounding vulnerability. The findings emphasize the interconnection of numerous factors contributing to susceptibility, underscoring the need for comprehensive and integrated strategies to address complex socio-environmental challenges.

3.3. Co-authorship author network

The minimum threshold for publications and citations were set as 1 and 60, respectively. As a result, 52 authors contributing to publications in the journal were identified. (Fig. 3) illustrates the co-authorship network of these authors, revealing the presence of 13 distinct clusters.

3.4. Most frequent or relevant words

This graph illustrates the frequency of specific phrases within a given context. The term "climate change" appears most frequently, highlighting its central importance to the discourse. Following this, "adaptive management" occurs significantly less often, indicating a notable but secondary emphasis. Terms such

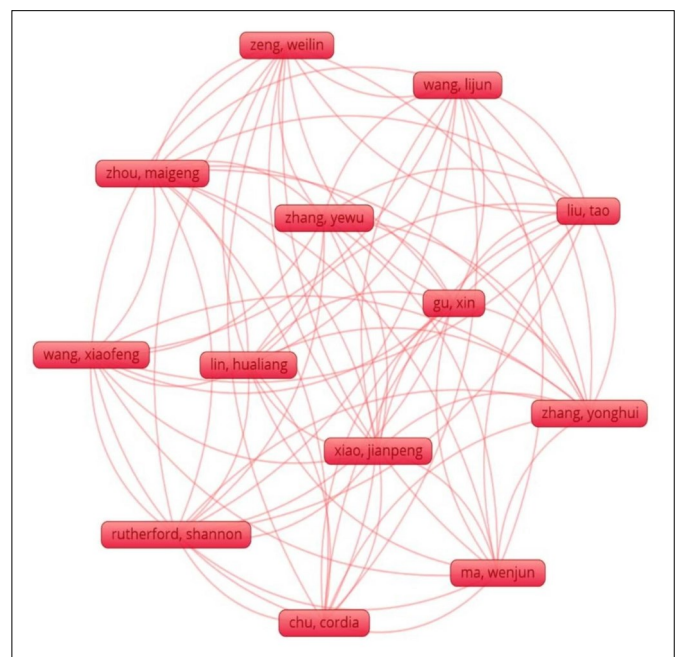


Fig. 3. Shows the article and collaboration network (Source: Vos viewer).

as "agriculture," "perception," and "risk perception" gradually bring attention to various aspects of environmental and cultural dynamics. Interestingly, the term "China" appears in conjunction with words like "agriculture" and "adaptation," suggesting the relevance of these topics in a specific geographical context. The relatively infrequent occurrence of terms like "human" and "article" may reflect their broader, less specialized usage. Overall, the table provides valuable insights into the key concepts and themes within the field under review, highlighting recurring topics and focal points in the discussion.

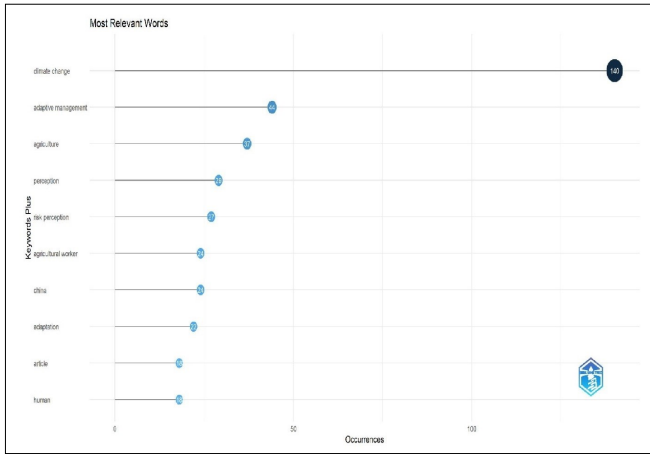


Fig. 4. Most frequent or relevant words used (Source: R studio).

3.5. Most globally cited article

The graph presents a list of several papers along with their corresponding DOIs, Total Citations, annual Total Citations (TC annually) and Normalized TC values. The paper "BERRANG-FORD L, 2021, NAT CLIM CHANGE" demonstrates significant scholarly impact, with the highest Total Citations of 212. Additionally, its impressive TC per Years significance is indicated by the fact that has the greatest Total Citations of 212. Additionally, it's impressive TC per Year of 53.00 underscores its continued relevance and influence within the field. In contrast, the work "COMOŽ H, 2015, MITIGATION ADAPT STRATEG GLOBAL CHANGE" has the lowest Total Citations and TC per Year, indicating a comparatively lower level of impact and recognition.

The Normalized TC values further enhance the analysis by illustrating the relative influence of each work for every year since its publication. Overall, the graph offers insightful data regarding these works' citation metrics and influence, assisting in the evaluation of their academic significance within the scholarly community.

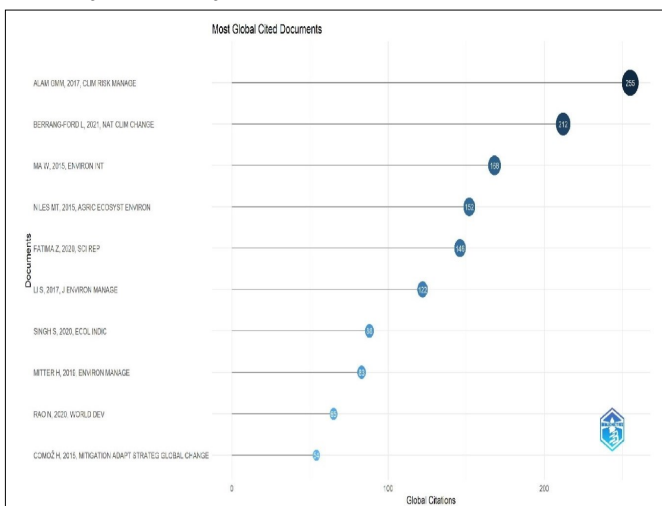


Fig. 5. Most globally cited articles (Source: R studio).

3.6. Most relevant authors

The graph presents the authors' varying article counts alongside the fractionalized representation of their contributions. Authors with higher fractionalized counts-such as Fischer AP and Wang J-have authored fewer articles overall but have made substantial contributions to each publication-possibly as main authors or through significant involvement in collaborative works. In contrast, authors such as Zhang Y exhibit lower fractionalized counts despite

having authored three papers, suggesting shared authorship or a comparatively smaller contribution per publication.

This data underscores the diverse roles that authors play in academic publishing, ranging from individual contributions to collaborative efforts. Understanding these dynamics is essential for evaluating research impact, authorship credit and the nature of intellectual collaboration within academic communities.

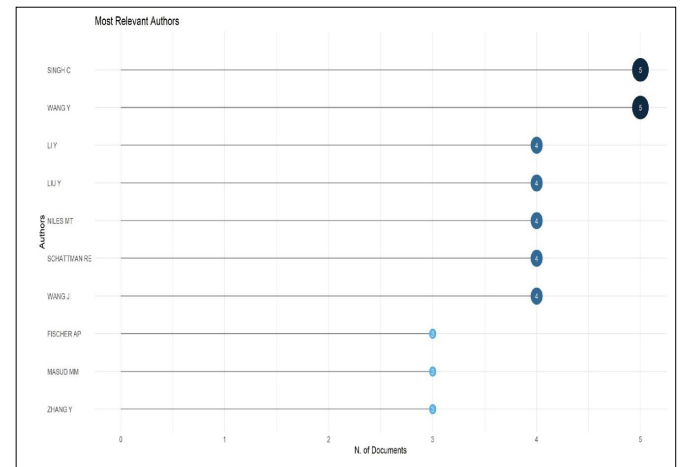


Fig. 6. Most relevant authors (Source: R studio).

3.7. Factorial analysis

The graph displays words along with their assigned clusters and corresponding dimensional values. These dimensions likely represent abstract features derived through dimensionality reduction techniques such as t-SNE or PCA. Words within the same cluster are presumed to share similarities in meaning or context. For instance, terms like "agriculture," "climate change," and "adaptive management" are grouped in Cluster 1, indicating thematic coherence related to environmental or agricultural topics. Similarly, terms such as "perception" and "risk perception" are grouped together, reflecting their conceptual alignment within the same domain.

This clustering reveals potential patterns or relationships among the terms, providing valuable insights into the dataset's underlying structure. By highlighting semantic relationships and thematic patterns, these analyses enhance the understanding and interpretation of the content.

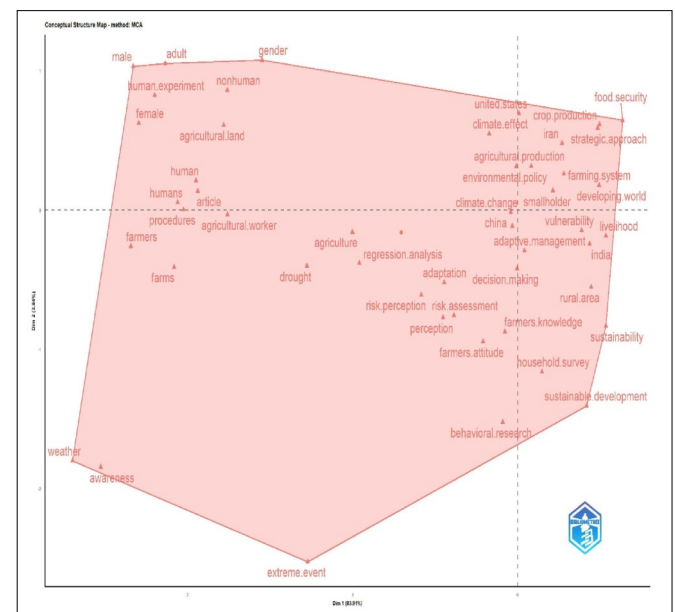


Fig. 7. Factorial analysis (Source: R studio).

3.8. Technological advancements

The use of technology and resource optimization in recent agricultural adaptation strategies in developed countries is highlighted. One notable trend is the enhancement of biodiesel production efficacy from *Jatropha curcas* L through the use of underwater high-voltage discharges. This technique, which involves the disruption of cell walls using pressure shockwaves, significantly improves oil extraction, achieving yields of up to 94%. Additionally, it enhances the usability of the residual materials for biogas production. This approach represents a sustainable model that combines energy efficiency with effective agricultural waste management (17).

3.9. Limitations

The findings from this study are subject to several limitations, which may affect the generalizability of the results. First, the reliance on a single research database (Scopus) may have excluded relevant studies from other databases, potentially reducing the comprehensiveness of the review. Second, the exclusion of patent databases overlooks insights from innovator related to adaptation technologies in agriculture. Third, the emphasis on English-language studies may have introduced linguistic bias, potentially excluding important research from non-English-speaking regions. Furthermore, the stringent inclusion criteria, while ensuring relevance and quality, may have resulted in the omission of valuable perspectives. Addressing these limitations in future studies would enhance the robustness of the findings.

Conclusion

This study concludes that traditional knowledge and social networks significantly influence farmers' decisions regarding the adoption or rejection of specific adaptation strategies. Climate-smart agriculture and early warning systems are employed to mitigate the challenges associated with climate variability, while access to extension services on climate-smart practices enhances farmers' adaptive capacity. Conservation tillage, agroforestry and improved livestock management help reduce greenhouse gas emissions from farming practices. Crop insurance schemes play a crucial role in assisting farmers to overcome financial crises resulting from climate-related vulnerabilities. Additionally, crop rotation enhances resilience to climate variability. Further investigation into the extension services related to early warning systems, climate modelling and remote sensing is needed to improve awareness of climatic variability.

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Authors' contributions

SR participated in designing the study framework and drafted the manuscript. AM conceived the overall research idea and provided guidance. MR supervised the study and coordinated the manuscript preparation. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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