PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–16
https://doi.org/10.14719/pst.5156

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REVIEW ARTICLE

Determinants of climate-smart agricultural technology adoption: A comprehensive systematic review

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OPEN ACCESS

ARTICLE HISTORY
Received: 19 September 2024
Accepted: 04 November 2024
Available online
Version 1.0 : 11 December 2024

Check for updates

Additional information
Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
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CITE THIS ARTICLE
Dhivya C, Murugan PP, Senthilkumar M, Asokhan M, Dheebakaran Ga, Gangai SR, Arunkumar R. Determinants of climate-smart agricultural technology adoption: A comprehensive systematic review. Plant Science Today.2024;11(sp4):01-16. https:/doi.org/10.14719/pst.5156

Abstract

Climate-Smart Agricultural (CSA) technologies are essential in enhancing agricultural sustainability and resilience in the face of climate change. However, the successful adoption of these technologies remains a complex challenge influenced by various factors. This research aims to provide a systematic review of the factors affecting the adoption of CSA technologies and thoroughly examine academic research in this rapidly developing study area. Scientific mapping was conducted, analytical techniques were used to understand the annual scientific production countries with the highest citations and co-occurrence network analysis was also done using the key search terms of CSA adoption research. The literature on determinants of CSA adoption is synthesized in terms of theories, contexts, characteristics and methods (TCCM) framework to propose future research directions.

Additionally, the study develops a conceptual framework incorporating the commonly mentioned antecedents, mediators, moderators and consequences in existing literature. Drawing upon an extensive review of peer-reviewed articles, this study categorizes factors into 3 main dimensions: Socio-Demographic and Socioeconomic factors, Farm and Land factors and Technological and Informational factors. This review of the research also reveals the impact of positive and negative aspects on CSA's adoption. In addition, this review summarizes the theoretical perspectives taken in this field of study. Furthermore, to develop this research domain, some interesting future research directions have been recommended by identifying understudied research areas.

Keywords

adoption; climate change; climate smart agriculture; determinants

Introduction

The population of the globe will rise from a current population of about 8 billion people to over 9.8 billion by 2050 (1, 2). The agricultural sector's most significant problem appears to be producing enough food for the whole population (3). Due to the limited amount of agricultural land available, substantial efficiency gains are needed (4). A significant change in agriculture is required to maximize production with limited resources. In many parts of the world, agricultural production is acknowledged to be among the most threatened by global climate change (5, 6). Any modification in the climate over some time, whether due to natural variability or human action (7). Food

production is primarily threatened by climate change, which includes increasing average temperatures of 1–4.5 °C (8), unpredictable precipitation and frequent weather fluctuation even with the strain from the food requirement aspect (9). Insect and pest outbreaks are also brought on by climate change and are likely to damage more crops (10).

Sustainable Development Goals, particularly Goal 13 as Climate Action and Goal 2 as Zero Hunger, emphasize the vital relationship between agriculture, climate change mitigation and adaptation and more significant sustainable development initiatives (11). In addition to raising agricultural output, achieving food security and eradicating hunger require strengthening agricultural systems' resistance to shocks and stresses brought on by climate change (12). Within this framework, CSA has surfaced as a comprehensive strategy to promote socioeconomic development, improve climate change resilience and steadily raise agricultural production (13).

"That sustainably increases productivity, resilience (adaptation), reduces or removes Green House Gas (mitigation) and enhances achievement of national food security and development goals" is how the Food and Agricultural Organization described CSA (1). CSA is an approach that overlooks the specific context and community-appropriate, adaptable results in favour of improving farming practices and ensuring food security in an unstable environment (14). When these goals are successfully attained, different innovative techniques are implemented, leading to reduced greenhouse gas emissions, higher yields and climate change mitigation, a phenomenon known as the ""triple win"" (1). The idea stresses context-specific solutions catered to regional circumstances and requirements while acknowledging the interdependence of social, economic and environmental elements influencing agricultural environments (15).

Compared to other approaches, CSA methods are easier to incorporate into food production processes and effectively lower climate shocks, satisfying the growing demand for food (16-18). The benefits of CSA techniques that increase agricultural production might improve the financial well-being of farmers (19) and the quality of the environment (20). CSA encompasses various practices, technologies and policies customized to certain socioeconomic and agro-ecological circumstances. Some of the technologies include agroforestry (21, 22); conservation agriculture (21); improved crop varieties (19); water harvesting and management (23); livestock management (8); climate information services (24) and integrated pest management. These practices are not mutually exclusive and are often combined to maximize the synergies and benefits.

Several studies have reviewed the literature to present an overview of the factors determining the adopting practices of CSA. The first objective is to evaluate the growth of literature on driving factors for adopting CSA practices that have expanded over time and the scientific mapping of CSA research. Based on the literature's synthesis, the second objective is to provide a conceptual framework for understanding the factors affecting CSA adoption phenomena. The third objective is to identify the gaps in the amount of information already available in this field of research to suggest directions for future investigation. This study has numerous implications, both academic and practical. The proposed conceptual framework illustrates this study's novelty.

The importance of this review lies in its ability to provide a holistic understanding of the factors influencing the adoption of CSA technologies. The review organizes the determinants of adoption into critical categories (e.g., socio-demographic and technological factors) and proposes a conceptual model that future research can build upon. It provides policymakers with data to create targeted interventions to overcome challenges and encourage the adoption of climate-smart technologies. By identifying understudied areas, the review guides future researchers toward areas that require further investigation. Non-Governmental Organizations and agricultural institutions can use the findings to design training programs, workshops and policy measures to increase awareness and facilitate adoption at the farmer level.

Methodology

Review Structure

A review is based on the theory, domain and method that can all be included in a Systematic Literature Review (SLR). Researchers synthesize research on a specific concept in theory-based systematic reviews (26-28). Systematic reviews on theory-based researchers put forth new hypotheses or evaluate current theories to improve them. A method-based review compiles the body of knowledge regarding a particular method (29). The most prevalent kind of SLR is domain-based SLR (30). Domain-based reviews can be carried out in 5 distinct ways, all centred on a study topic.

This review is based on a hybrid review, combining bibliometric analysis and a structured review. After thoroughly examining the textual material, bibliometric analysis is conducted using R software for the scientific mapping of the literature domain. A structured review identifies gaps in the literature and offers a thorough synthesis of the information (31). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement was the primary tool utilized to find pertinent articles on CSA use among the farmers, which is described in Fig. 1. Researchers can find and filter for eligibility requirements and data extraction for analysis with the help of the PRISMA approach. Additionally, this approach lets the researchers outline the research issue, provide criteria for both inclusion and exclusion and promptly review the enormous database (32).

The PICo (Population or Problem (P), Interest (I) and Context (Co)) research question development method was utilized in the formulation of the research question for this study (33). Three primary factors in this review were developed using the PICo development method: farmers, CSA practices, and factors. As a result, the researchers formulated their research question, ""What are the factors influencing CSA practices among the farmers?"".

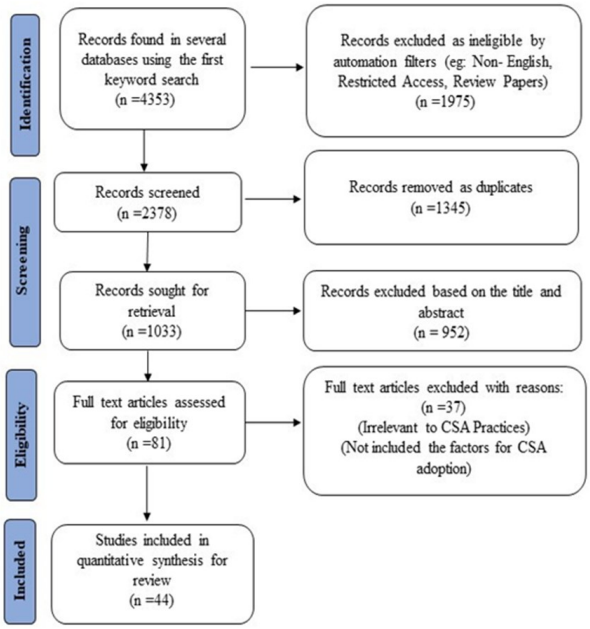

Fig. 1. PRISMA flowchart.

Search strategy

The review determined which keywords to use while searching for papers in the databases. The combinations of keywords with the categories covered in the algorithms are "CSA" "CSA practices," “CSA interventions,” “CSA practices,” “climate-smart agricultural technologies,” “climate resilient agriculture”, “factors,” “factors influencing,” “determinants” and “drives.”. The previously mentioned keywords were employed with the Boolean Operators "AND" and "OR" to look for comparable published articles in a variety of databases. Systematic reviews aim to find all relevant papers that match predetermined inclusion criteria through a well-planned search strategy that frequently involves several electronic databases (26). The shortlisted keywords were used to search articles on databases such as Scopus, Web of Science, and ScienceDirect. For this SLR, all papers with the chosen keywords in the title, abstract or keyword lists were considered.

Journal Selection and Inclusion/Exclusion Criteria

Identification Phase

Three steps make up the systematic review process: (1) Identification, (2) Screening and (3) Eligibility. The process began with identifying keywords and continued with the search for related terms. Using the search keywords, 4353 records were identified in Scopus, Web of Science and Science Direct databases.

Screening Phase

The screening phase involves systematically reviewing and evaluating the titles and abstracts of potentially relevant studies to determine their eligibility for inclusion in the review. The articles were included in specific inclusion and exclusion criteria for screening, as explained in Table 1. The initial step is to include research articles, excluding review articles, books, conference proceedings and book chapters. Secondly, only English-language papers were included. Reducing the review to English-language publications improves uniformity and standards because it makes it easier for reviewers to communicate and work collaboratively while evaluating research. Thirdly, the publications were chosen between the periods of 2016 and 2024. This assessment period can highlight the emerging trends, innovative approaches, and technologies in CSA interventions. By including studies from this time frame, the systematic review can draw upon a larger pool of relevant literature to comprehensively analyze the factors influencing adoption. Fourth, only open-access journals were included because they remove difficulties in knowledge dissemination by making research freely available to anyone with internet access. By incorporating open-access publications, SLRs can ensure that findings are available to a larger audience, such as researchers, practitioners, policymakers and the wider public, regardless of institutional affiliation or subscription access. The replicability of the systematic review is enhanced by open-access studies, which are typically simpler for other researchers to obtain and evaluate. Based on the exclusion criteria, 1975 articles were excluded. Afterwards, 1345 articles were eliminated based on duplicates obtained in one or more databases. Again, 952 articles were dropped based on the abstract and title.

Eligibility and Inclusion

A total of 81 full-text articles have entered the eligibility phase. Then, 37 were excluded from the criteria since it didn’t specify the intervention of CSA practices. More articles were excluded as they did not focus on any factors or determinants in adopting CSA practices. The articles not related to the study were also removed. Finally, 44 articles are selected based on the inclusion criteria.

Findings and Discussion

Detailed information, such as the research title, the author's information, the year of publication and the journal of publication of 44 articles, is included in the review. The articles were thoroughly examined to have an in-depth understanding of the factors influencing climate-smart agricultural technologies.

Table 1. Inclusion and exclusion criteria.

Criteria	Inclusion	Exclusion
Literature type	Research articles	Review articles, book series, book chapters, conference papers
Language	English	Non-English
Timeline	2016-2024	<2016
Access type	Open access	Restricted access

Scientific mapping of CSA adoption research

Advancement of CSA adoption research over time

The annual scientific production of CSA research publications is presented in Fig. 2. It displays the total amount of research publications published between 2016 and 2024 in the area of factors impacting the adoption of CSA practices. Analyzing the temporal distribution of publications on CSA might reveal important information about how academic research has developed throughout the period. The 40 % (18 papers) of the publication were done during the year 2023; around 23 % (10 papers) of papers were published in 2022; 11 percent (5 papers) of publication during 2010, 9 % (4 papers) of the paper were published in 2020; only 4 % of research articles in 2019; 6 % of research publication in 2018, where 1 paper was published in 2017 and 1 paper was published up to January 2024. These papers are selected based on the inclusion criteria mentioned above. It shows that significant growth in the number of publications was witnessed between 2020 and 2023. One contributing factor might be the global COVID-19 pandemic that began in 2020 and raised awareness of the need for food security and resistance to health threats and climate change. This might have increased the study and development of determinants of factors influencing the CSA technology and processes.

Sources Production Over Time

The paradigm shifts of articles published in high-quality journals are indicated in Fig. 3. journals such as Heliyon, International Journal of Climate Change Strategies and Management, Sustainability, Climate, Agriculture and Food Security, Climate Risk Management, Environment Challenges and Frontiers in Sustainable Food Systems from the period of 2016 to 2024. The journal Heliyon published the maximum number of articles (5 papers), followed by sustainability (4 papers), International Journal of Climate Change Strategies and Management (3 papers), Environmental Challenges (4 papers) and Frontiers in Sustainable Food Systems (4 papers).

Countries with the Highest Citation in CSA Research

According to the graph in Fig. 4, Kenya had the most citations, with 215 citations and Ethiopia was second with 168 citations. Other countries, like South Africa, which has 99 citations; Germany, which has 62 citations, Vietnam, Thailand, India, Ghana, Japan and China, have fallen between 4 and 45 citations. This shows that Kenya and Ethiopia are the most prominent and active nations when doing and disseminating CSA research. The fact that these countries experience various kinds of climate change impacts and have varying degrees of susceptibility and capability for adaptation could be one reason for this outcome. Governments, academic institutions and international organizations may have provided funds and resources for studies to determine what influences the uptake of climate-smart agricultural methods.

Co-occurrence Network Analysis using Main Keywords

The co-occurrence network analysis was generated using the interconnected terms in the context of CSA practices, represented in Fig. 5. It offers critical insights and connections based on the study of the data. Different colours and sizes represent the various frequencies of terms. The nodes were interconnected with one another, where the central node, climate change, indicates its prominence and frequency within the dataset. The central node is directly connected to several terms, such as agricultural practices, greenhouse gases and mitigation. The articles concentrated on the factors that influence the CSA but also on concepts of adoption, knowledge and perception. Clusters of related terms surround the central node.

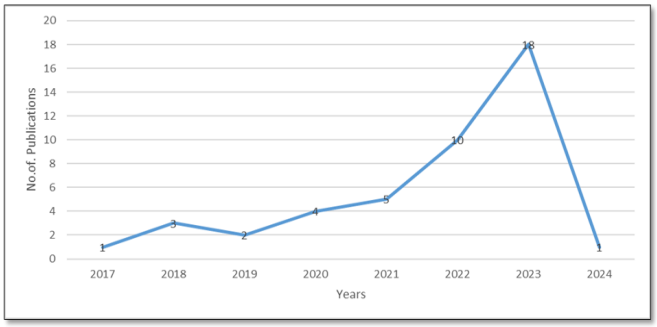

Fig. 2. Annual scientific production of determinants of CSA.

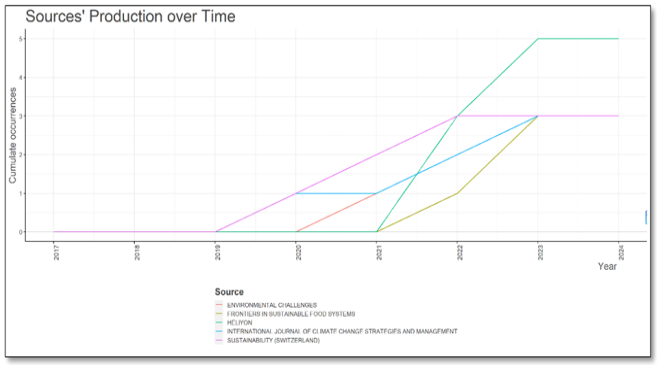

Fig. 3. Publication of journals of determinants of CSA adoption.

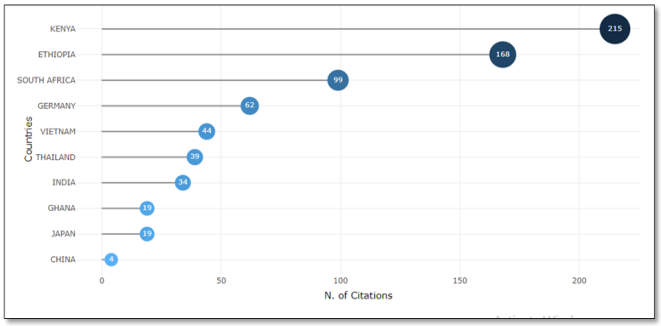

Fig. 4. Countries with the highest citation in CSA adoption research.

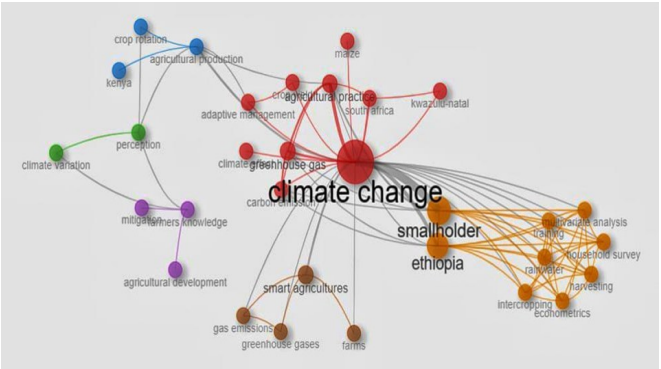

Fig. 5. Co-occurrence network analysis of research key terms.

Research Settings

The distribution of articles compiled in this part is based on the countries from which the data were collected. While collecting primary data from a sample is not necessary for conceptual research, we exclusively considered empirical research for our analysis. This systematic literature review observed that all the research papers (44 papers) are based on empirical research done for primary data collection. Country-wise distribution is presented in Table 2 and it shows that the highest number of research studies were conducted in Ethiopia (9 papers) and other research papers are from Kenya (6 papers), Nigeria (6 papers), India (5 papers), Ghana (4 papers), South Africa (3 papers), Vietnam (2 papers) and each paper from the countries of Mali, China, Thailand, Myanmar and the Congo Basin. The mentioned countries may have made large investments in agricultural research and development, especially when it comes to mitigating and adapting to climate change. With this financing, more research and publications about CSA technology may exist. Countries may have established partnerships with universities, international organizations and funding agencies, resulting in collaborative efforts to develop and apply CSA. In these countries, a significant percentage of the population lives in agriculture. The productivity and stability of agricultural systems are threatened by climate change, which might harm rural lives and food security. Consequently, a compelling reason exists to embrace behaviours that improve climate change resilience.

Research Design and Data Collection

In terms of the methodologies employed, we synthesized research papers on CSA. The synthesis of research methods is demonstrated in Table 3. The table shows that the majority of the studies adopted a survey-based design (34, 35) and employed mixed-method research (36-38). Since the study is focused on the factors influencing the adoption of climate-smart agricultural technologies, mixed-method research is carried out, incorporating both qualitative and quantitative approaches (39). The qualitative approach gave insights into exploring the determinants for adopting CSA practices. Simultaneously, quantitative surveys were administered to measure adoption rates and they revealed a statistical association between the factors and adoption rates. A minimum number of papers only focused on qualitative techniques. Table 4 exhibits that the majority of the studies used the cross-sectional household survey, which was used to get a baseline understanding of the socioeconomic circumstances, attitudes toward climate change and present agricultural practices among households in a given area (34, 35, 40, 41). Utilizing an established structure and an organized set of questions, structured interviews facilitate quantitative evaluation by enabling participants to provide answers (42-44). A flexible questionnaire can be utilized in semi-structured interviews, integrating pre-planned questions with the chance for unstructured questioning (45). Some papers have implemented focus group discussions involving conversations among participants led by an instructor to extract opinions from everyone on a particular subject. This approach might reveal common experiences, foster lively discussions and examine perceptions of climate change and the factors affecting climate-smart agricultural practices (46). Some papers used the technique of in-depth interviews with each respondent. During an interview, it provides a thorough examination of a particular subject. It can be implemented with farmers, agricultural experts and government representatives (Department of Agriculture at the Village, District and State levels) (47). Some research papers applied the field observation method (48) and conducted the key informant interview with the experts or stakeholders, which provided knowledge about climate-smart agricultural intervention and additional insights into policy frameworks and community-level initiatives.

Table 3. Research methods used in determinants for adopting CSA practices.

Research methods	References
Cross-sectional household survey	(8, 18, 23, 34, 37, 40, 47, 49-53, 56)
Structured interview schedule	(19, 38, 42-44, 57)
Semi-structured interview	(46)
Focus group discussion	(19, 38, 46-48, 50, 51)
In-depth interview	(38, 48, 51)
Field observation	(23, 38, 43, 48)
Key informant interview	(19, 50, 51, 54)

Table 2. Countries and number of publications.

Sl. No.	Country	2016-2017	2018-2019	2019-2020	2021-2022	2023-2024	Total
1.	Ethiopia		1		4	3	8
2.	Kenya		2	1	2	3	8
3.	Nigeria				2	4	6
4.	India			1	2	3	6
5	Ghana		1		1	2	4
6.	South Africa			1	1	1	3
7.	Vietnam			1	1		2
8.	Mali					1	1
9.	China					1	1
10.	Myanmar		1				1
11.	Thailand		1				1
12.	Uganda					1	1
13.	Congo Basin					1	1
14.	Western Africa	1					1
	Total	1					44

Statistical Analysis Techniques

In this section, we synthesize the studies of CSA on data analysis methods. Table 4 indicates that many quantitative techniques were used to analyze factors influencing climate-smart agricultural technologies. Many researchers have conducted descriptive statistics analyses, which provide summary information about the data (42, 50). The principal component analysis is the dimensionality reduction technique for reducing the variables and identifying the significant factors. This method assists in creating homogenous groups within but distinct from one another following the identification of multiple CSA technologies (8). Another technique is cluster analysis, which is used to classify the related data items into clusters according to the similarities of CSA technologies (55). The multivariate probit regression model allows us to analyze multiple binary outcomes (57) simultaneously. It is an extension of binary probit regression to handle the multiple-correlated dependent variable. Binary logistic regression models were used to assess the factors influencing farmers' adoption of mitigation and adaptation techniques and their views of climate variability (41). One popular method for estimating models of ordered CSA categories is the ordered probit model (56). The analysis used in other papers is the generalized ordered logit regression model and composite score index (42, 57). Implementing the inverse-probability-weighted regression adjustment (IPWRA) to calculate the effect of CSA adoption on GHG emissions and the generalized Poisson regression model to determine the factors influencing farmers' participation in GHG emission practices (40). The mixed logit model was also used for the study because it addresses discovered and suggested intentions for farmers' adoption behaviour (58). The other analyses that were used for the studies are the Tobit regression model (49), multinomial endogenous switching regression (59) and multinomial logistic model (76).

Table 4. Analytical techniques used in the determinants for adopting CSA practices.

Analytical techniques	References
Principal component analysis	(34, 35)
Cluster analysis	(35)
Multivariate probit regression model	(19, 34, 35, 60-62)
Descriptive statistics	(35, 42, 51, 57)
Binary logistic regression model	(2, 22, 41, 48)
Ordered probit regression model	(56, 63, 64)
Ordered logit regression model	(57)
Poisson regression model	(40)
Inverse-probability-weighted regression adjustment (IPWRA)	(40)
Composite score index	(42, 57)
Gendered ordered probit regression model	(42, 58)
Mixed logit model	(58)
Tobit regression model	(49)
Multinomial endogenous switching regression	(59)
Multinomial logistic model	(65)

Theoretical Perspectives

Theories used in CSA research

This study additionally looked at the theories that have been put forth over time to see what makes climate-knowledgeable agricultural technology more likely to be adopted. Table 5 demonstrates how several theories were applied in the CSA study. The application of numerous ideas indicates that CSA research is still in the early stages because CSA methods contribute to creating a sustainable and profitable environment while also being resistant to climate change (66).

Table 5. Theories used in the factors determining the CSA adoption research.

Theory	References
Theory of planned behaviour	(22, 38, 51, 68)
Theory of utility maximation theory	(19, 35, 61)
Rational choice theory	(61)
Random utility theory	(42, 61)
Gender and development theory	(37)
Diffusion of innovation	(68)
Entrepreneurial orientation	(68)
Behavioural models	(64)

Theory of Planned Behaviour

TPB is an analytical framework frequently used to explain and forecast a person's behaviour. TPB primarily focuses on an individual's goal-oriented behaviour and deliberate decision-making (67). The concept has been used in several studies to explain factors influencing the adoption of CSA practices. The theory states that perceived behavioural control, attitudes and societal norms, all impact people's intentions to adopt certain CSA practices (22). Social norms may influence farmers' adoption decisions in the area, their attitudes toward CSA technology and their perceptions of their own abilities to accept and use these technologies (68).

Utility Maximization Theory

UMT has an immediate effect on human behaviour in general and the behaviour of farmers in particular. The utility maximization theory serves as the foundation for adaptability in decision-making (69). When it comes to agricultural techniques, farmers implement climate-smart technologies if the anticipated benefits equal the drawbacks of their existing methods. The theory considers how dependent and explanatory variables interact with one another, explaining why human behaviour is unpredictable (19).

Random Utility Theory

A popular topic in economics and consumer behaviour research is random utility theory (RUT). It is a framework for simulating personal decisions made from multiple options. RUT states that people select the course of action that maximizes their utility, which is an estimate of preference or level of satisfaction (70). Random utility theory explains why different farmers may select various methods for adapting to climate change. Options vary because of a variety of factors, including personal preferences, local conditions, risk aversion and resource availability (61).

Rational Choice Theory

According to RCT, social phenomena are the result of reasonably interpreted individual choices. Decisions are made rationally when they satisfy the requirements of decision theory's consistency and are appropriate for accomplishing particular objectives within the limitations of the circumstances (71). The farmers evaluate various adaption strategies' costs (work, resources) and benefits (productivity improvements). Rational farmers implement climate-smart technologies if the expected benefits justify the costs. Rational choice theory illustrates why certain farmers decide on sustainable farming techniques in response to climate change (61).

Diffusion of Innovation Theory

Everette M. Rogers proposed the theory that the adoption of technology is primarily driven by attributes of innovation itself rather than solely by individual beliefs (72). It was adopted the diffusion innovation theory to examine the factors affecting the adoption of CSA practices (68).

Entrepreneurial Orientation

The theory refers to an organizational attribute where firms consistently support and manifest entrepreneurial behaviour. It becomes a defining characteristic of the organization. It incorporates managerial philosophies, decision-making practices, organizational elements and strategic behaviour (73). The primary dimensions of entrepreneurship orientation are innovation, risk-taking and proactiveness, which improve technology adoption in farming. Innovation in CSA is embracing and modifying methods that will enhance environmental responsibility, resource utilization and adaptability. Regarding CSA, EO is essential in determining how farmers and organizations accept and apply new techniques and technologies (74). Entrepreneurial orientation helps to promote environmentally friendly agricultural growth by coordinating practices with objectives for productivity and climate resilience (68).

Synthesis of Frequently discussed variables indeterminants of CSA adoption

This review aims to create a conceptual framework that incorporates the antecedents or independent variables, mediating variables and Consequences or Dependent variables, which are documented in the CSA literature. Table 6 illustrates how the antecedents are synthesized in CSA research. The literature proposed the set of factors, specifically Socio-Demographic and Socioeconomic Factors, Farm and Land Factors, Technological and Information Factors and Socio and Cultural Factors, that predominantly

Table 6. Antecedents of CSA research

Selected factors	Impact directions	Sources
Age	+	(22, 25, 35, 46, 47, 50, 59, 61)
	-	(19, 50, 51, 61, 84)
Gender	+	(19, 22, 35, 44, 58, 59)
	-	(2, 38, 44)
Education level	+	(22, 34, 38, 40, 42, 47, 48, 50, 51, 54, 57, 58, 60, 61, 84)
	-	(44, 79)
Marital status	+	(37, 50)
	-	(79)
House hold size	+	(40, 44, 57)
Income	+	(2, 29, 34, 35, 37, 38, 42, 47, 48, 51, 54, 57, 61)
	-	(42, 79)
Farming experience	+	(22, 37, 42, 54, 56, 84)
Land size	+	(22, 34, 35, 42, 51, 53, 57, 61, 84)
	-	(50)
Land tenure	+	(23, 58)
	-	(38)
Land ownership	+	(54)
	-	(52)
Livestock holding	+	(19, 34, 41, 51)
Access to credit	+	(19, 23, 35, 38, 44, 53, 54, 63)
	-	(61)
Exposure to media	+	(29, 42)
Farm distance	+	(19, 38)
	-	(42, 57)
Market distance	+	(19, 53, 59, 63)
	-	(49, 50)
Training	+	(19, 23, 41, 47, 52, 56)
	-	(34)
Land tenure	+	(37, 38)
Access to extension services	+	(34, 35, 38, 40, 44, 46, 50, 51, 53, 54, 61, 62, 84)
	-	(22)
Membership to agricultural association	+	(19, 42, 47, 50, 57, 59)
Socio-cultural benefits	+	(38)
Climate change perception	+	(42, 57, 62)
Primary occupation	+	(61, 63)
Accessibility of practices	+	(38)
Access to climate information	+	(51, 59)
Availability of climate-smart technology availability	+	(43)
Awareness about climate change	+	(43)
Achievement motivation, risk orientation, scientific orientation	+	(29)
Social and cultural limits	-	(65)

influence the farmer's responses toward CSA. According to the reports in the literature, adoption of climate-smart agricultural practices (42), acceptance of climate-smart technologies (64), climate change adaptation strategies (44), choice of Indigenous practices (38) and agricultural productivity are found to be outcomes of the responses of farmers. Further, the elements' influence on the responses of the farmers to CSA are mediated by Attitude towards the Climate Smart Agricultural Practices and Perception of Climate Change.

Antecedents of Response to CSA

Socio-demographic and Socioeconomic factors

These factors strongly influence the acceptance and effectiveness of climate-smart agricultural techniques. The Socio-demographic and socioeconomic factors, including age, education, gender, marital status, household size and primary occupation, influence the farmer's decision to pursue agricultural practices in the majority of communities with limited resources (75).

Age

The older farmer acquires deeper agricultural experience and exposure to both previous and current climate conditions. Young farmers, on the other hand, may have long-term intentions of executing farm investments in technologies whose benefits can be observed eventually (22, 25). The elder farmers tend to reduce labour-intensive and management-intensive activities compared to younger farmers (76). The farmers' age significantly influenced the adoption of micro-doses of organic manure (90). According to a study, older farmers are more likely to understand the value of and implement this approach (90). The average age of the farmers was 45.46 ± 9.36 years, suggesting that they were in their productive and financially independent years, capable of adapting and coming up with innovative approaches for climate change adaptation (61). As farmers became older, the adoption and implementation of CSA increased, but only to a certain extent. After that point, farmers' ages observed a fall in the adoption of these techniques. Farmers also have a tendency to decrease their farm expenses by using innovative technologies or exploring them as they get older (35, 46). In Ha Tinh province of Vietnam, there is a higher adoption rate of climate-smart agricultural technologies among the older farmers, whereas, in Thai Binh and Bac Lieu provinces, younger farmers are more interested in adopting the climate-smart agricultural technologies since older farmers are less likely to take more risks than the younger farmers. Based on a study, the use of climate-smart agricultural technologies significantly affects farmers' age and educational status (47). The study also concluded that adopting the CSA technology negatively influenced production experience and age.

Gender

Gender positively impacts the possibility of increased demand for CSA techniques (35). It was derived that households headed by men could benefit from improved agricultural varieties and rainwater harvesting compared to women (19). Due to their more significant domestic duties than men, women often lack the time to obtain extension services or other relevant information regarding the importance of CSA techniques. Male-headed households were able to adapt to the impacts of climate change than household women (44). Gender positively influenced adoption of agroforestry practices in KwaZulu-Natal Province, South Africa (22). In Bac Lieu province, gender has a beneficial impact on the uptake of enhanced stress-tolerant cultivars and water-saving techniques but a negative impact on other provinces, such as Thai Binh and Ha Tinh of Vietnam, for adopting the CSA technologies. Gender is negatively significant in adaptation strategies. Female smallholder potato growers were more likely than male farmers to employ CSAPs. This may be because women handle the majority of farming tasks, particularly in Africa, which encourages them to adjust to climate change and prevent damage to the food security of their households (2). Compared to men, female farmers appear to be less likely to implement CSA techniques (59).

Educational Level

Household heads educational status improves their capacity to gain and implement knowledge to help them make better decisions about adopting CSA. The utilization of better livestock breeds also rises with a farmer's level of education. Higher educated farmers may have chosen cow breeds that are profitable and environmentally friendly in order to mitigate the consequences of these hazards because they were more aware of the problems associated with climate change (77). The adoption of improved varieties, planting trees, composting, windbreaks and micro-doses of mineral-based fertilizer were found to be independently correlated with the education level of rice growers (50). In Nigeria, farmer's educational status is positively correlated with their perception of climate change. Thus, farmers' chances of perceiving climate change improve with the time spent in formal education they have received (44). The proportion of education showed a favourable correlation with cassava productivity, and it indicated that increasing the number of years that cassava farmers spend receiving a formal education will raise the yield of cassava (61). It was derived that increased use of CSA technology was seen among respondents with higher education levels than among those with lower education levels (54). Education facilitates access to essential knowledge and enhances awareness of training instructions. The extent of CSA practice adoption is positively influenced by the household head's education, which was found to be important and it demonstrates that better-educated farmers are more easily utilizing modern CSA techniques and advancements (57). Educational status was essential in lowering greenhouse gas emissions (40). Higher education has been associated with increased access to technological information (78). Higher-educated fishermen are more likely to respond to climate change more efficiently (48).

Marital Status

Married people are more likely than single people to be admitted into cooperatives; marital status favours the use of improved seed (50). Comparatively, male farmers who are single or divorced and married smallholder farmers have implemented CSA activities on their agricultural land (37).

Household size

Household size research has indicated that smaller households would have more difficulty adjusting to new farming methods since their decision-making and allocation of resources are more controllable (12). On the other hand, larger households may find it more difficult to effectively coordinate labour and resources, which might slow down the adoption procedure. (79) suggested that having more family members results in increased labour and information exposure, generating more ideas towards adaptation to the effects of climate change. Conversely, it was found that while large families were less inclined to adopt labour-intensive CSA techniques, small family sizes welcomed the advances and hired staff to make them a reality (34). It was also derived that financial limitations in bigger households may prevent adopting more advanced and sustainable agriculture methods (40). Therefore, a household's size may favour or negatively impact its ability to participate in greenhouse gas emission practices.

Income

Their income levels significantly influence the smallholder farmers' adoption of CSA techniques. Farmers with higher incomes might have more significant resources available, allowing them to spend money on CSA technology like irrigation systems, drought-tolerant seeds or methods for conserving soil (37). It has shown that participants with higher household incomes adopted CSA technology more successfully than respondents with lower household incomes (54). As money increased, more CSA technologies were adopted. Thus, farmers with more incomes were more likely to manage crops, protect crops, manage soil nutrient levels and use seed management techniques and technologies. Farmers with ongoing access to extension services are more likely to combine horticulture crops with other crops to increase their farm income (62). The decision to use the CSA models is heavily influenced by income (47). There is a negative correlation between CSA adoption and the primary source of income (79).

Farm and Land Factors

Farm and land factors are major factors impacting the implementation of CSA techniques. These variables include different facets, including farming experience, land size, land tenure livestock holding, farm distance and market distance, which might help or impede the adoption of CSA technologies.

Farming Experience

Female farmers stated they are able to alter the times of planting as adaptation techniques because of their farming experiences and the availability of a secure ownership structure. Farmers with experience can recognize the fluctuations in the climate and modify their farming schedules accordingly. Experience in farming increased the rate of CSA adoption, which may be explained by smallholder farmers learning from their experiences and gradually switching from traditional to cutting-edge technologies that meet their needs at the moment (42). CSA adoption is positively influenced by farming experience, which is due to the fact that farmers who gain farming experience will be able to identify the advantages of CSA techniques that were implemented early on and will welcome new CSA practices. More experienced households are better equipped with the know-how for effectively managing their on-farm operations (22).

Land Size

Land size is a household's entire land area. Massive areas of land enable farmers to share the risks of losses related to climate change and diversify their cattle and crop alternatives (77). The size of the farmland statistically and positively influenced the degree of adoption of the CSA technique in both the lower and higher user groups (57). Farmers who owned larger farms used more CSA adoption strategies, suggesting that supporting farmers in implementing CSA methods is beneficial. The dispersion of land may hamper the adoption of the CSA, as farmers with more land embraced more CSA techniques (42). According to research by (52), farmers who own larger farms tend to be wealthier and are more inclined to modify their farming methods, giving them more resources to allocate towards adaptation to climate change plans.

Land Tenure

The research probably emphasizes how stable land tenure enables farmers to invest in long-term CSA initiatives like agroforestry and conservation agriculture, whereas unstable land tenure may impede CSA adoption since farmers may be reluctant to make modifications to their land without assurances of land stability (58). Additionally, land tenure was found to be highly relevant, indicating that having secured land serves as a motivator to increase investment and the intensity of soil and water conservation techniques (23). CSA adoption decisions are influenced by land tenure security (37). Different land tenure statuses result in varying adoptions of CSA practices. Farmers that own permanent land typically implement CSA techniques that promote long-term recovery, like agroforestry practices (2).

Land ownership

Smallholder farmers who own their land are incentivized to invest in their operations. In contrast, those who lease their farmlands see fewer profits, which negatively impacts their acceptance of CSAs (54). The pursuit of agricultural benefits is heightened by clear land ownership, motivating farmers to implement CSA methods (23). In Kenya, land ownership is positively correlated with changes in farming methods (52).

Livestock Holding

The utilization of intercropping, improved crop varieties, and rainwater harvesting are positively affected by livestock ownership. In this connection, improved varieties positively correlated with livestock holding, whereas intercropping and rainwater harvesting showed a negative correlation (19). Since livestock are produced alongside crops in integrated crop-livestock structures, there is a greater potential for greenhouse gas emissions as a result of intestinal fermentation, managing manure and changes in land use corresponding to feed production (34).

Farm Distance

The distance between farms and villages influenced the farmers' decision to use indigenous methods. Because they

tolerate such landscape features, native crops like red sorghum and millet were chosen to be grown in stony and hilly landscape locations (38). It have shown that farmers' decisions to adopt certain agricultural practices are heavily influenced by the distances between their farms and homes (46). Since higher distances can discourage farmers from attempting new or suggested technologies or approaches, the distance between the farm and the homestead is anticipated to correlate adversely with the degree of CSA adoption (42). In contrast, a statistically significant negative relationship between the respondents' farming distance from their homestead and the lower degree of CSA adoption (57).

Market Distance

The market distance measures a farmer's distance from their closest local marketplace. If the farming community houses are far from the market centre, they might not have access to means of transportation. As a result, they lose more significant assistance from organizations that could encourage using climate-smart farming techniques. The negative connection showed that farmers' ability to employ superior cattle breeds declines with increasing distance between the household home and the closest local market (19). Farmers who live miles from the market centre cannot use the facilities and would likely ask for more assistance from the relevant organizations, which could lead to a rise in the use of CSA techniques (83). The distance to market significantly and adversely affected the degree of preference for CSA technologies (63). Farmers in the provinces of Bac Lieu and Ha Tinh make CSA decisions based in part on market distance. The acceptance of CSATs is adversely correlated with market distance but positively correlated with the availability of climate information, confidence regarding extension agents' expertise and involvement in both social and agricultural groups (59).

Technological and information factors

Technological and Information factors are essential in influencing the adoption of CSA. Access to credit, access to extension services, membership in the Agricultural Association, exposure to media and training attended are included in this factor.

Access to credit

The adoption of CSA methods is positively and significantly impacted by loan availability (19). In contrast, financial availability has a major and detrimental influence on implementing CSA approaches (52). Farmers' use of agricultural inputs like fertilizer, insecticides, new seeds and agricultural equipment like tractors, harvesters and planters are all influenced by their access to financing (52). The findings concluded that CSA utilization rates were more significant among individuals with access to agricultural loans than those without (54). The results emphasized how crucial it is to access credit because CSA technologies require farmers to make significant financial investments to use them. Mobile-based financing options impacted the adoption of all CSA technology categories and improved crop quality (35). Additionally, statistically significant was credit availability. This implies that the chances of medium, high and zero preference for CSA technologies will decline with increased financing availability.

Access to Extension Services

Extension services contribute significantly to the advancement of CSA practices. Farmers were more inclined to use CSA technologies if they connected with agricultural extension services because those services helped farmers perceive the benefits of using them. It was suggested that farmers will be more inclined to embrace technological advances if they have access to extension services (40). Farmers with more access were more likely to be included in the coffee and maize agricultural systems and he also found that, compared to their male counterparts, more females did not have access to extension services. This could be explained by social and cultural conventions and the absence of adequate timing frames for extension services among females. It might be explained by customs and cultural norms or the lack of suitable timetables for the extension for women (80). The adoption and utilization of CSA are predicted to increase with farmers' greater access to extension services. (46, 81). Extension services positively impact the adaptation of agricultural technology through several channels. First, giving farmers extension services enhances their accessibility to information and human capital. Secondly, it strengthens access to agricultural financing and the distribution of inputs. Thirdly, it is the primary channel for providing smallholder farmers access to agricultural research and development outcomes (82). Adoption of CSA practices is positively correlated with and significantly influenced by access to government extension services. It increases the possibility of implementing drought-resistant varieties, crop rotation and crop diversification; however, the adoption of microirrigation isn't statistically significant (43). For example, in Ethiopia, farmers who receive extension services are more likely to implement CSA techniques like applying farmyard manure, minimizing tillage and improving fodder (60). The smallholder farmers lacked sufficient access to agricultural extension services, including better inputs, seedlings and farming techniques (38).

Membership in an Agricultural Association

Membership in an association influences access to public spaces, especially in rural areas. Agricultural associations give farmers a forum to discuss their difficulties with their peers and receive advice on resolving them. The degree of adaptation of the CSA method was positively and statistically significantly impacted by membership in an association or group with an agricultural focus (42). Because of the cooperatives' funded improved seed programs, rice growers' adoption of improved seed was positively impacted by cooperative membership (50). Membership in agricultural groups positively impacts the adoption of various CSAT packages that support the findings (47, 59).

Exposure to Media

The degree to which the surveyed small-scale growers in Mthonjaneni and Mhlathuze Municipality adopted the CSA was positively influenced by media exposure. The media exposure had a major impact on their adoption of CSA technologies (29). It was demonstrated that exposure to mass media raises the possibility that CSA practices will be adopted.

Training Attended

The households received training on climate-smart farming methods, with the likelihood of using better crop varieties and livestock types. Farmers who had obtained instruction in agriculture were more inclined to believe that climate change is a constant (56). Farmers' perceptions of climate variability were positively correlated with their access to agricultural training (41). Training in CSA is crucial for changing farming methods; its results were most notable and advantageous in Mozambique (52). Participation in awareness-raising and training workshops on soil and water management strategies or climate change adaptation is strongly and favourably connected with adopting stone bunds and composting (23). The training attendance, training and participation in a sociopolitical group positively influence adaption decisions (47).

Access to Climate Information

Climate information should enable farmers to make better-informed decisions on adaptation (51). Farmers should be able to make more informed decisions about adaptation using climatic information. Access to climatic data increases the likelihood of implementing certain behaviours (51). Information about climate change makes farmers realize how important it is to use CSA techniques to minimize crop yield loss and enhance their quality of life, which awakens a primitive need to adapt to climate change (42). This indicator is positively related to adopting CSA practices (59). When farmers have access to meteorological and climate data, they become more cognizant of changes in rainfall and temperature. This helps them decide how to enhance their resilience and adapt to the consequences of climate change (62).

Mediators

Mediators are the processes, procedures, or mechanisms that mediate the relationship between antecedents and consequents. Those operate as a link between the antecedents (the things that cause change) and the outcomes (the things we desire to happen), which is crucial in bridging the gaps in the complex environment of CSA. Perceptions of climate change (42, 57) and attitudes toward climate-smart agricultural practices mediate the adoption of CSA technologies.

Perception of Climate Change

There was a statistically significant difference in the sample household's opinion of the effects of climate change (57). Farmers believed climate change would negatively impact the farming sector, particularly for high users. Furthermore, if farmers believed climate change would significantly negatively impact food production, they would use more CSA techniques (57). The degree of adoption of CSA practices was positively and statistically significantly impacted by perceptions of the impact of climate change (42). Farmers who see an overall decrease in rainfall are also more likely to implement agroforestry and soil conservation techniques. If farmers believe that the temperature is rising, they are more likely to adopt CSA methods (85). Farmers who have access to weather and climate information become more conscious of and educated about variations in temperature and rainfall (62). Farmers who experience a reduction in rainfall are also more likely to implement agroforestry and methods for soil conservation. Farmers are more inclined to implement CSA techniques if they believe the temperature rises. Adopting crop rotation, tolerance of drought seeds, soil conservation and planting schedule adjustments are strongly influenced positively by the perception of increased temperatures (85, 86). Farmers anticipating more flood catastrophes are better equipped to implement several CSA techniques, including drought-resistant varieties, crop rotation, changing planting times and agroforestry (62).

Attitude towards Climate-Smart Agricultural Practices

Attitude is defined as "the extent to which an individual makes a positive and negative evaluation of performing the behaviour". Positive attitudes foster CSA adoption. Farmers' decision to adopt CSA practices is substantially impacted by their positive attitude toward these activities (38, 87, 88). The socio-psychological factors, such as farmers' attitudes toward the benefits they would like to receive, their perceptions of the practices' ability to control their behaviour and social pressure to adopt better practices, impacted smallholder farmers' decisions to adopt CSA practices (87). The specific information, perspectives and attitudes were essential and crucial in helping rural families decide whether to implement agroforestry (22). On the contrary, farmers' lack of knowledge about better methods exacerbates this view, leading to an unfavourable attitude toward implementing climate-smart agricultural techniques (84). Farmers' attitudes toward CSA procedures are influenced by their perceptions of the practices; thus, examining how they respond to these impressions is critical.

Consequences or dependent variables

The CSA adoption practices are a vital response to the growing threats that climate change poses to agricultural sustainability and global food security. Farmers are increasingly realizing more and more how important it is to modify their conventional farming practices to minimize hazards brought on by climate change and increase resilience in various agro-ecological settings. A range of context-specific solutions is included in CSA practices, like precision irrigation systems, conservation tillage methods, agroforestry, drought-tolerant varieties and animal management approaches adapted to shifting weather patterns. The many outcomes or consequences were identified through the SLR, which is explained in Table 7. Most of the studies focused on the domain of adoption of CSA practices. The other frequently studied dependent variables in the CSA context are Climate change adaptation Strategies (44, 51, 52, 58), Use of Indigenous Practices (38), Acceptance of CSA practices (64) and increasing agricultural productivity (29, 53, 89).

Development of a Conceptual Framework for the Determinants of CSA

A conceptual model in Fig. 6 has been established based on the literature's synthesis by including frequently reported factors in the literature on CSA. The model illustrates that socio-demographic and economic factors, farm and land

Table 7. Consequents of CSA research.

Variables	Sources
Use of climate-smart agricultural practices	(19)
Choice of indigenous practices	(38)
Adoption of agroforestry practices	(22)
Improved rice varieties, alternate wetting and drying, parboiled rice, rice straw composting	(50)
Increases agricultural productivity	(29, 53, 61, 89)
Farmers' adaptation to climate change	(51)
Farmers' perception of climate variability	(41)
Choice of ex-ante climate risk adaptation strategies	(52)
Adoption of CSA	(2, 22, 29, 42), (50, 59, 60, 79, 84)
Climate change adaptation strategies	(44)
Acceptance of climate innovative technologies	(64)
Choice of alternative CSA practices	(65)

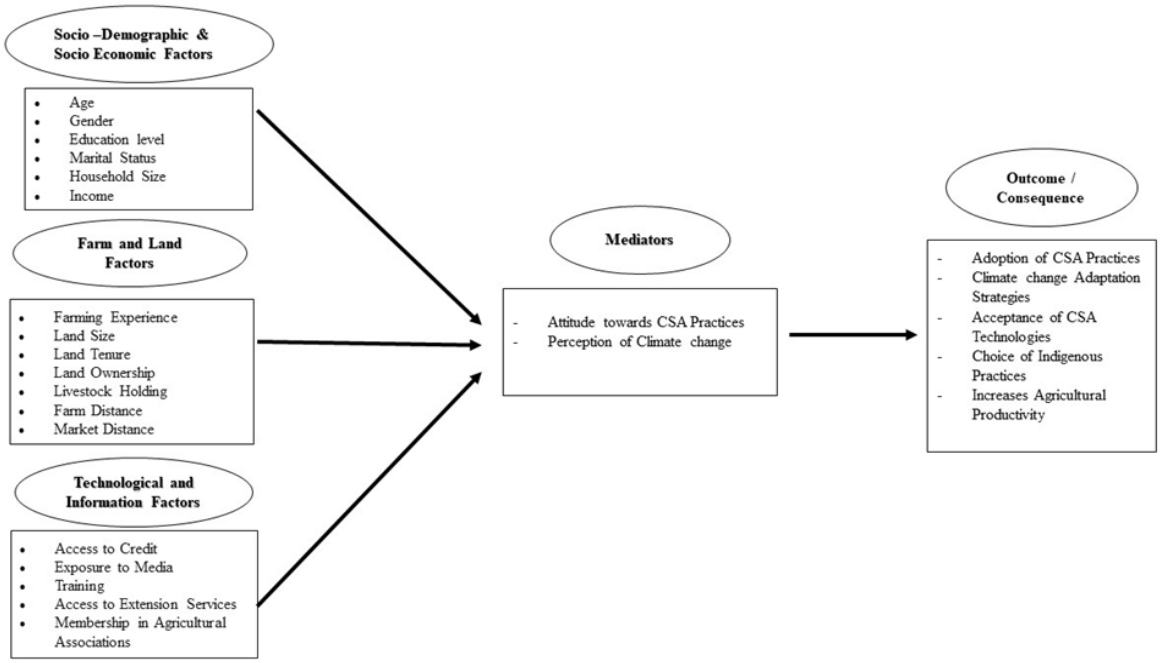

Fig. 6. Conceptual framework.

factors and institutional and information factors influence the adoption of CSA technologies. The attitude toward climate-smart agricultural practices and perceptions towards climate change mediate the association in CSA contexts between the antecedents and outcome variables. The framework exhibits the adoption of CSA practices, Climate change adaptation strategies, Acceptance of CSA technologies and Use of Indigenous practices as critical determinants of results in the CSA context.

Future Research Directions

This technique of structured literature reviews also recommends future research directions in the CSA domain that help accomplish the next research objective. The current analysis suggests future directions for CSA domain research using the TCCM framework (28). T represents theory development, C represents context, C represents characteristics and M indicates methodology in the TCCM framework (90). This framework offers a valuable strategy for evaluating existing research and creating new research agendas in an area by using the lenses of TCCM. Discussion of the research agenda for the future was developed utilizing the TCCM framework.

Academic and Practical Implication

Academic Implication

Firstly, this study looked at the most recent developments in this field of research by conducting a systematic literature review on CSA. Although the survey of CSA has been conducted over a long period, there are still inconsistencies and a limited contribution to the detailed investigation of the systematic literature review. This study thoroughly examines CSA adoption research based on the TCCM framework. The current dynamics of the CSA adoption concept were examined and its evolution was analyzed in this study. The most recent findings and advancements in CSA technology will be included in the literature review using the inclusion criteria by focusing on the work published between 2016 and 2024. During this period, policy frameworks and activities about agriculture and climate change may have evolved, influencing CSA technology implementation strategies, funding objectives and research agendas.

Secondly, the study summarized the numerical theories used in the factors determining CSA adoption research and suggested 2 alternative theories (value-based adoption model and institutional theory) that can be used in

CSA research in the future. These foundations advance the theoretical underpinning of CSA literature.

Thirdly, synthesizing the CSA adoption literature, this review developed a conceptual framework comprising widely used variables reported in the studies. The antecedents were categorized into various groups, including 3 factors. This framework provides an initial phase towards additional empirical research studies.

Fourth, descriptive analysis was performed using the R studio to facilitate the quality assessment and screening of included studies with different databases. The study uses the biblioshiny to visualize the publication trends over time and help the researchers to identify the key themes, topics and concepts within the literature. This makes it possible to create interactive dashboards, summarize findings and present data in an understandable way.

Finally, this systematic literature review concluded that there were specific gaps in the CSA adoption research and suggested several directions for further investigation based on the synthesis and review. Future research should focus on several aspects, including theory, contexts, characteristics and methods.

Practical Implication

Policymakers can use the conceptual framework to pinpoint the crucial determinants influencing the implementation of CSA technology. This information can be utilized to direct the creation and execution of focused policies and initiatives meant to remove specific challenges and encourage farmers to accept CSA technologies. Development organizations, Non -Governmental Organizations and agricultural extension services can create capacity-building initiatives designed to meet the factors mentioned in the conceptual framework. These initiatives could include demonstration plots, workshops and training sessions to increase farmers' awareness of CSA technology and practices and develop their skills in these areas.

Limitation and Conclusion

As with previous SLRs, this study has several limitations as well. First, a set of exclusion and inclusion criteria is used to select published publications for analysis and conclusions in the CSA adoption review. Only articles that meet the requirements are reviewed further. Thus, the findings cannot be generalized to all the CSA adoption research. Secondly, only papers published in English as a language were eligible for inclusion in this SLR. Consequently, specific research published in other languages may have been excluded. These limitations could cast doubt on the generalizability of the results.

In conclusion, this study's objective was to examine the theories, research settings and methodologies found in the literature. After the literature is synthesized, a conceptual framework that illustrates the connections between antecedents, mediators and consequences is developed. Finally, this SLR recommended future research directions to further the literature on factors influencing the adoption of CSA technologies in terms of theories, context, characteristics and methods. Overall, this work enhances the determinants of the adoption of CSA technologies.

Acknowledgements

The authors express their deepest gratitude to the Department of Agricultural Extension and Rural Sociology for their invaluable guidance and support throughout this study-special thanks to the Chairman and advisory members for their valuable feedback and constructive suggestions on the manuscript.

Authors' contributions

DC was responsible for the conceptualization and formation of the original manuscript. MPP contributed through conceptualization and supervision. SM focused on idea development and reviewing. AM and DGa were involved in the collection of the review data. GSR provided supervision, while AR handled writing, reviewing, and editing tasks.

Compliance with ethical standards

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

Ethical issues: None

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