frontiers | Frontiers in Environmental Economics

TYPE Systematic Review
PUBLISHED 03 April 2024
DOI 10.3389/frevc.2024.1356335

OPEN ACCESS

EDITED BY
Gideon Danso-Abbeam,
University for Development Studies, Ghana

REVIEWED BY
Mohamed Esham,
Sabaragamuwa University, Sri Lanka
Kehinde Oluseyi Olagunju,
Queen's University Belfast, United Kingdom

*CORRESPONDENCE
Maíra Finizola e Silva
✉ maira.finizolaesilva@uantwerpen.be

RECEIVED 15 December 2023
ACCEPTED 12 March 2024
PUBLISHED 03 April 2024

CITATION
Finizola e Silva M, Van Schoubroeck S, Cools J and Van Passel S (2024) A systematic review identifying the drivers and barriers to the adoption of climate-smart agriculture by smallholder farmers in Africa.
Front. Environ. Econ. 3:1356335.
doi: 10.3389/frevc.2024.1356335

A systematic review identifying the drivers and barriers to the adoption of climate-smart agriculture by smallholder farmers in Africa

Maíra Finizola e Silva[1]*, Sophie Van Schoubroeck[1], Jan Cools[1,2] and Steven Van Passel[1]

[1]Department of Engineering Management, Faculty of Business and Economics, University of Antwerp, Antwerp, Belgium, [2]Institute for Environment and Sustainable Development, University of Antwerp, Antwerp, Belgium

Climate change impact, food security concerns, and greenhouse gas emissions are pressuring agricultural production systems in developing countries. There is a need for a shift toward sustainable food systems. One of the concepts introduced to drive this shift is climate-smart agriculture (CSA), endorsed by international organizations to address multifaceted challenges. Despite widespread attention and support, the adoption of CSA among African farmers remains low. This systematic literature review aims to shed light on the factors influencing CSA adoption amongst African farmers. Within the articles identified as relevant, over 50 CSA practices and more than 40 factors influencing CSA adoption were distinguished. These influencing factors can be categorized as personal, farm-related, financial, environmental, and informational. The focus of this review is to identify and explain the overall impact (positive, negative, or mixed) of these factors on CSA adoption. Overall, many factors result in mixed effects, only some factors have an unambiguous positive or negative effect on CSA adoption. For instance, educational level emerges as a key personal factor, positively impacting CSA adoption, along with positive influences from farmers' experience and farm size among farm-related factors. Financial factors reveal distinct patterns, with income from farming and access to credit positively influencing adoption, while off-farm income exhibits a negative effect. Environmental factors, though less researched, indicate positive impacts related to changes in rainfall patterns, temperature, and droughts. Lastly, informational factors consistently exhibit a positive effect on CSA adoption, with training, access to extension, group memberships, climate information, and CSA awareness playing crucial roles. These findings provide valuable insights for policymakers seeking to enhance CSA adoption in Africa, offering a nuanced understanding of the multifaceted dynamics at play.

KEYWORDS

climate-smart agriculture, CSA, adoption, sustainable agriculture, Africa, farmers

1 Introduction

- While the agricultural sector and the associated food systems are key components of Africa's economy contributing to about 15% of the continent's total GDP (OECD-FAO, 2016), the sector is also unsustainable and has limited climate resilience (World Bank, 2011; Sono et al., 2021; Global Plan of Action, 2022). This is especially problematic in light of climate change and population growth. Climate change will alter rainfall and temperature patterns, water availability, the frequency of extreme events, and ecosystem functioning (FAO, 2023). All influence agricultural production and increase the vulnerability of people who depend on food systems for their livelihoods (FAO, 2013; Lipper et al., 2014). At the same time, it will become challenging to ensure food security for the growing population. According to the United Nations (2021), Sub-Saharan Africa (SSA) currently accounts for over 1 billion people and is expected to double in population by 2050. By the end of this century, the population in SSA is likely to quadruple to roughly 4 billion people (UN/DESA, 2021). At the same time, more people will be living in cities, where a trend of income and consumption growth is observed. Urbanization and rising incomes are driving the increase in the consumption of animal products in developing countries. This means that agricultural production will have to increase by ~60% by 2050 to satisfy the expected demands for food and animal feed (FAO, 2013). It is safe to say that there is an urgency for policymakers to prioritize the development and implementation of specific adaptation strategies in SSA's agricultural industry to mitigate the effects of climate change and enhance agricultural productivity and sustainability (Omotoso et al., 2023).
- These concerns have been circulating for years. The worldwide food crisis from 2007 to 2008 made apparent that food security remained a volatile issue for the poorest. In addition, this crisis highlighted that agricultural production systems needed a new direction in developing countries to address the multiple interlinked challenges, including climate change, food security, and greenhouse gas emissions (Chandra et al., 2018). In the same period, the Intergovernmental Panel on Climate Change (IPCC) began focusing on the dual relationship between climate change and agriculture, which was previously weakly understood. The nature and extent of their relationship were researched, revealing that agricultural systems are likely contributors to and are impacted by climate variability and change (Chandra et al., 2018). Since the very first IPCC report, actors have recognized the need for agriculture to adapt to climate change (Tegart et al., 1990). However, it was not until 2009 that the concept of climate-smart agriculture (CSA) was introduced in a paper by the Food and Agricultural Organization (FAO) that called for greater efforts in climate mitigation and adaptation. The idea of CSA emerged from a growing concern over food security, given the rapidly changing demographics and climate (Mann et al., 2009). Since 2009, the concept has gained significant traction and has often been mentioned at the forefront of policy debates.
- CSA aims at enhancing the resilience of farm systems to the effects of climate change through three main pillars: (1) sustainably increasing agricultural productivity and incomes; (2) adapting and building resilience to climate change (adaptation); and (3) reducing and/or removing greenhouse gases emissions (mitigation), where possible. CSA aims to contribute to the achievement of the sustainable development goals (SDGs) by integrating the three dimensions of sustainable development (economic, social, and environmental) by jointly addressing food security and climate challenges (FAO, 2013). However, "it is important to emphasize that CSA is not a new set of practices to be promoted to farmers, but rather an integrated approach to the implementation of agricultural development policies and programs that strives to improve food security, livelihoods, and resilience under the realities of climate change, while at the same time capturing mitigation co-benefits where possible" (Rosenstock et al., 2016, p. 11).
- CSA features several strengths. Firstly, it brings together existing sustainable agricultural practices as well as policies and institutions in the context of climate change. Multiple challenges faced by agriculture and food systems are addressed simultaneously and holistically, which helps avoid counterproductive or conflicting policies, legislation, and/or financing (FAO, 2013; Lipper et al., 2014). A second strength is its flexibility, according to Lipper et al. (2014), CSA differs from the "business-as-usual" approaches by emphasizing the capacity to implement context-specific and flexible solutions supported by innovative policies and financing actions. CSA responds to the growing demand for a comprehensive framework integrating climate change, food security, and sustainable agriculture (Lipper and Zilberman, 2018). Third, the concept is applauded for its "triple wins", aiming to enhance agricultural productivity and incomes, build resilience to climate change, and reduce greenhouse gas emissions simultaneously (Lipper et al., 2014). A fourth strength is the concept's attention to the trade-offs made when engaging in CSA. "The emphasis on explicitly identifying trade-offs in the CSA approach is a reaction to the lack of such consideration in many of the sustainable agricultural approaches which focus only on the benefits obtainable, ignoring costs and barriers. The result has been disappointingly low adoption of sustainable agricultural techniques, despite decades of efforts and funds to support them" (Lipper and Zilberman, 2018, p. 24). In sum, as is highlighted in the Climate-Smart Agriculture Sourcebook by the FAO (2013), CSA effectively addresses interconnected challenges, adopts a context-specific approach, identifies barriers to adoption, aligns policies, and prioritizes smallholders' livelihoods. Numerous case studies support these strengths, demonstrating the diversity of CSA practices and their positive impacts on farmers facing climate change, emphasizing the importance of community involvement, capacity building, political goodwill, and an enabling legal framework (Nyasimi et al., 2014).
- Whilst several international organizations such as the FAO and the World Bank have endorsed and promoted CSA,

others have expressed sharp criticisms (Karlsson et al., 2018). One major topic for debate, revolves around the ambiguous definition of CSA, fostering diverse interpretations and controversies (Lipper and Zilberman, 2018). This ambiguity allows a broad range of agricultural practices, potentially harmful to climate and farmers, to be labeled as "climate-smart", raising concerns of corporate "greenwashing" (Neufeldt et al., 2013; Anderson, 2021). Secondly, concerns also arise from the top-down nature of some social innovations, neglecting local farmers' knowledge and needs (Matthews, 2017; Alexander, 2019). A third critique, argues that CSA insufficiently addresses social issues, neglecting the "Do Not Significant Harm Principle" and favoring agro-industrial expansion at the expense of smallholder voices (Karlsson et al., 2018). Civil society organizations also raise concerns about corporate influence within the Global Alliance for Climate-Smart Agriculture (GACSA) and the potential shift of the mitigation burden onto the world's poorest (Lipper et al., 2014; CIDSE, 2015; Climate Smart Agricultural Concerns, 2015). The framework is accused of overlooking enduring inequalities in both production and consumption, thereby overlooking how these inequalities contribute to vulnerability to climate change and food insecurity (Taylor, 2018). Fourthly, critics highlight the insufficient empirical evidence supporting CSA's integration into the global development agenda (Lipper et al., 2014; Rosenstock et al., 2016), emphasizing the need for robust studies on drivers and barriers to adoption (McCarthy et al., 2011; Arslan et al., 2013). Robust studies focusing on how to improve the understanding of what works where and why in different farming systems are urgently needed to facilitate the identification of what constitutes "climate smartness" in different biophysical and socio-economic contexts (Lipper et al., 2014). It is necessary to showcase the broader impact of CSA practices and technologies beyond individual plots or sites, to influence a wider audience, institutions, and policy-makers (Westermann et al., 2018). This review focuses on this last criticism, aiming to clarify drivers and barriers to the adoption of CSA beyond individual experiences. This is done by bundling and comparing the results from different studies.

- Although CSA is a debated concept and framework, it has received, and still receives, a lot of attention from international (development) organizations. This is translated into big development projects with financial and technical assistance to facilitate the widespread implementation of CSA in Africa. For instance, between 2016 and 2018, the World Bank financed US$3.8 billion to endorse CSA projects in 30 African countries (World Bank, 2018). Currently, the World Bank is developing CSA Investment Plans worth over US$2.5 billion (World Bank, 2023). Moreover, when analyzing the Nationally Determined Contributions (NDCs) of African countries, 45% (24 countries) identified the agricultural sector as the topmost priority for adaptation, and 94% of the NDCs mentioned CSA as an important adaptation measure (African Development Bank, 2019). Despite the efforts of several stakeholders, it remains challenging to increase CSA adoption rates. For (smallholder) farmers to adopt CSA, they need to be willing to and comfortable with learning new farming approaches, place trust in new knowledge and associated advisory support systems, and engage in transactions within unfamiliar markets (Ogunyiola et al., 2022). In addition, some actors use certain practices and/or technologies not because it is useful but because they seek benefits related to the project, such as obtaining credit, prestige, or cash, which is called "pseudo-adoption" (Kiptot et al., 2007). This demonstrates that implementing a project and teaching actors about new practices and/or technologies does not guarantee the uptake of those practices and/or technologies; there are many different variables at play. Therefore, theories on innovation diffusion and adoption are essential. These theories offer insights into how new practices are embraced within a social system, considering factors like innovation characteristics, communication channels, social networks, and perceived benefits (Long et al., 2017; Teklu et al., 2023). Integrating these theories helps understand CSA adoption dynamics and develop effective strategies amidst climate change. The theory of innovation diffusion outlines how agricultural technologies are adopted through communication and knowledge exchange (de Oca et al., 2021). It identifies key characteristics influencing adoption rates, like relative advantage and compatibility (Mlenga and Maseko, 2015). Additionally, it describes adoption as a cognitive process, progressing through knowledge acquisition, persuasion, decision-making, implementation, and confirmation (Meijer et al., 2015; Teklu et al., 2023).
- With this context in mind, this systematic literature review aims to answer the following research question: what factors influence the adoption of CSA amongst African farmers? Despite successful case studies and promising research results, many agricultural technologies and practices, including those qualifying as CSA, are not being adopted by farmers in developing countries and are thus not achieving their full potential (Westermann et al., 2018). CSA as well as other practices such as conservation agriculture, farm-level natural resource management, and sustainable intensification practices face the same challenge (Kassie et al., 2015; Brown et al., 2017; Stevenson et al., 2019). Despite decades of research, typical rates of adoption remain low, ranging between <1% to about 30%, depending on the region and the method used to assess the adoption (Kassie et al., 2015; Brown et al., 2017; Stevenson et al., 2019).
- Several studies about CSA adoption have been published in the last years with varying results, therefore, this review paper aims at structuring and summarizing the results while attempting to find a pattern in how different factors influence the adoption of CSA among African farmers. This review paper is structured as followed: the context has been sketched in the introduction, clarifying what CSA is as well as its strengths and weaknesses. In the next section the method, a systematic review, will be discussed. Continuing with the results and discussion where the main findings are summarized and examined. Finalizing this paper with concluding remarks, recommendations, and research limitations.

2 Method

2.1 Data collection

A systematic literature review identifies pertinent and reliable literature using a predetermined protocol to achieve a certain objective or answer a research question. These reviews enable the identification and exploration of the best evidence, contradictory findings, and gaps in the existing literature (Gupta et al., 2018). For a review to be "systematic" it should aim at answering a specific research question, follow a pre-defined protocol, and comprehensively review all the available information (Uman, 2011; Gupta et al., 2018). This systematic literature review aims to identify the factors influencing the adoption of CSA in Africa.

To investigate the research question raised by this study, this systematic review has been conducted in accordance with the reporting standards outlined in the Systematic Evidence Synthesis (ROSES) framework. The ROSES framework aims to improve the quality and transparency of reporting in the environmental field by providing guidelines and a review protocol (ROSES, 2023). The ROSES review protocol (see Supplementary Table 1) was followed when preparing for this paper, screening articles to include or exclude, and writing this systematic review.

The literature search was conducted using the Web of Science (WoS) database in November 2023. The search queries were: "climate smart agriculture AND adoption AND Africa," "climate-smart agriculture AND adoption AND Africa," and "climate-smart agriculture AND uptake AND Africa". The search queries were applied on the title, topic, and abstract. The search was further refined by only including articles written in English, specifying the publication period (2019–2023), and focusing on peer-reviewed original articles. This recent time frame was chosen to ensure that the information presented in this review is current and reflective of the most recent developments in the field. These search queries generated 207 hits. After removing the duplicates 170 articles remained.

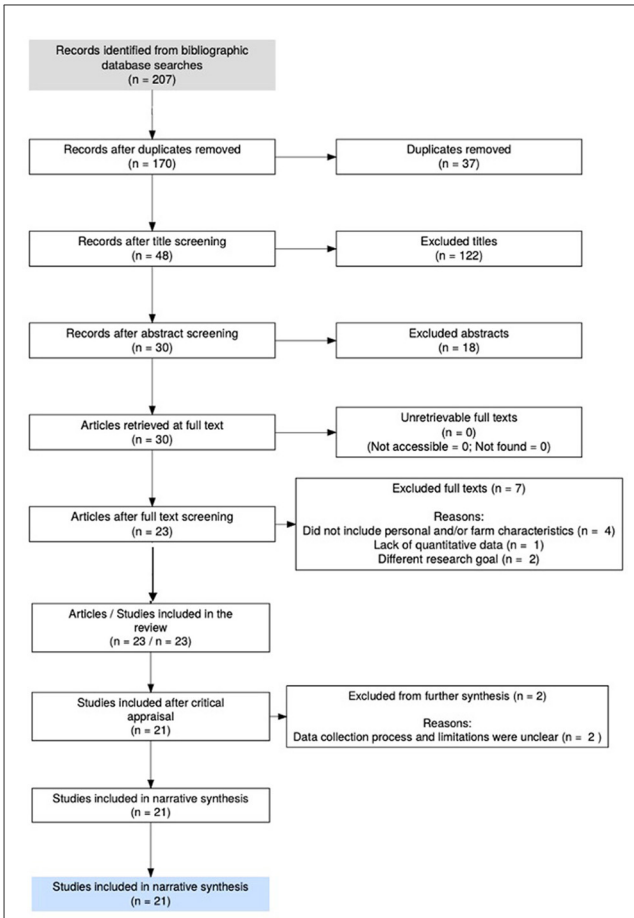

FIGURE 1
Systematic review flow chart. Flow chart created with the ROSES tool (Haddaway et al., 2017).

2.2 Data screening

The WoS articles that appeared following the search query were exported into Excel where they were screened following different steps. The flow of this process is demonstrated in Figure 1. First, the title of each article was screened systematically. The title needed to refer to the (dis)adoption of CSA, when it was not immediately clear if the article could be relevant for this review inclusion was ensured if the titles featured terms such as perception, adoption, obstacles, challenges, engagement, lessons, uptake, barriers, constraints, opportunities, or preferences, or synonyms of these words. Moreover, since this article is not about upscaling CSA, the adoption of other sustainable practices related to CSA, or only about one sustainable practice (e.g., conservation agriculture), these articles were removed from the review. In addition, review articles or studies solely using qualitative methods were also removed. Following these criteria resulted in the exclusion of 122 articles.

The second round of screening of the remaining 48 articles was done based on the abstract of each article. After screening all abstracts, 18 articles were excluded. The main reason articles were excluded in this stage was the lack of data or information about factors influencing the adoption of CSA.

The third step entailed gathering important information from each article and reading them thoroughly. For each article the following information was gathered: author names, title, journal, publication year, abstract, where the research was conducted, which method was used, size of the sample, and the main results related to the (dis)adoption of CSA.

The 23 articles that remained after this process were then subject to a critical appraisal to guarantee good quality articles. It was important that the sample size was large enough (>99 respondents) and that the sample strategy was clearly described. Similarly, the data collection process must be clearly described and standardized. Next, the statistical method used needs to align with the study objectives; solely qualitative studies were removed. Lastly, the study limitations need to be acknowledged and discussed. Articles that did not comply with two or more of these requirements were removed from the final list of articles. Two articles that did not describe the data collection process nor the study limitations clearly were removed. In both articles

it was unclear how the data was collected (e.g., which type of interview) and how it was standardized. In addition, it was unclear who collected the data (e.g., enumerators, researchers, etc.). The limitations of the research were also not discussed.

2.3 Data analysis

Each included article was carefully reviewed, focusing on sections pertaining to the drivers and barriers influencing CSA adoption. The practices and factors influencing CSA adoption, as delineated in the articles, were systematically summarized in Excel to facilitate a comprehensive understanding of patterns and distinctions. Notably, an observation emerged that many studies concentrated on five to ten specific CSA practices (e.g., conservation agriculture, crop rotation, intercropping, etc.), while some addressed CSA adoption holistically. Methodological variations, such as the use of percentages vs. narratives detailing positive or negative effects, prompted the need for a structured presentation to enhance clarity and coherence across diverse studies.

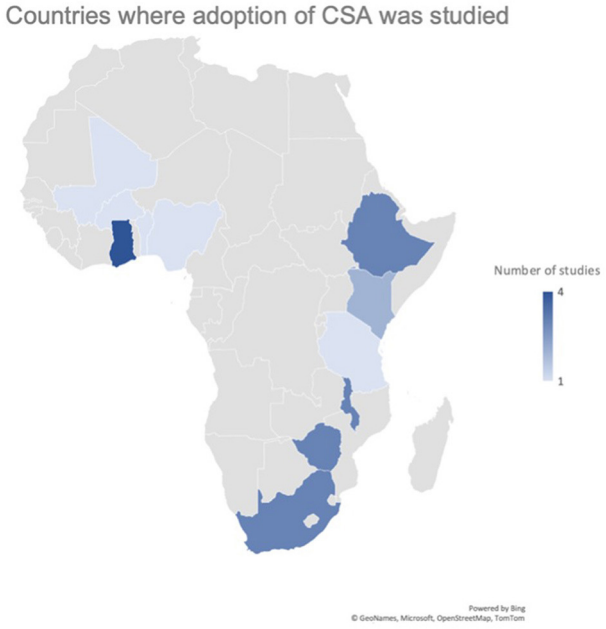

FIGURE 2
Countries included in the 21 studies. Two studies collected data from multiple countries.

3 Results

3.1 General observations

After going through the steps denoted in Figure 1, 21 articles from 2019 to 2023 researched and discussed the factors influencing the adoption of CSA amongst African farmers and met the predefined criteria. A full article list can be found in Supplementary Table 2. All studies were concentrated in one of 11 African countries, mostly on the South-East side of the continent, denoted in Figure 2. In general, large data samples were employed, with only three out of the 21 studies having sample sizes of fewer than 300 farmers.

3.2 Discussed CSA practices

As previously noted in the introduction of this review paper, CSA comprises a compilation of existing practices. Across the 21 WoS articles analyzed, over 50 distinct CSA practices were identified, with most articles addressing between five to ten practices. While some studies assessed the individual impact of each practice, others examined the combined effects. However, there may be some discussion about how or why certain practices are categorized as CSA, such as the spiritual invocation of rain (Moutouama et al., 2022) and fodder and forage production (Zampaligré and Fuchs, 2019).

To get a better overview of the practices, it was opted to group them into 11 categories (see Table 1). Some practices such as cover cropping, mixed cropping, and intercropping are discussed in 11 articles, whereas other practices are only discussed in one article.

3.3 Factors influencing adoption

In the 21 WoS articles used for this review, over 40 factors or independent variables, influencing the adoption of CSA amongst African farmers were discussed. This paper focused on recurrent factors mentioned consistently across multiple studies, ensuring a robust and widely applicable analysis. This approach enables a nuanced understanding of the main influences driving CSA adoption in Africa while maintaining clarity and relevance in the discussion. Therefore, all factors that were only mentioned in one study (e.g., the influence of receiving remittances, being a member of a faith-based group, etc.), were left out. In total, 25 factors were researched in multiple studies and will be further discussed in the next sub-sections. The factors were subdivided into five groups: personal, farm-related, financial, environmental, and informational factors. Figure 3 denotes the general effect of each factor on CSA adoption whereas Supplementary Table 3 gives an overview of how the factors influence the adoption of specific CSA practices. The following subsections give a generalized summary of the effects of each factor. To enhance readability, consistent references to individual articles throughout the text have been omitted. Instead, a consolidated summary is presented in Supplementary Table 4. This table provides an overview of which articles investigate specific factors and whether they report positive, negative, or mixed effects.

3.3.1 Personal factors

The exploration of personal characteristics, including gender, age, marital status, household size, educational level, and farmers' risk attitudes, across various articles reveals nuanced insights into their impact on the adoption of CSA. Even though the impact

TABLE 1 CSA practices and the number of times they were studied.

Water focused practices		**Livestock focused practices**	
Use of wetlands	1	Stress tolerant/improved livestock management	3
Irrigation	5	Oxen in the fields	1
Rainwater harvesting	2	Mixed farming (crop—livestock)	3
Spiritual invocation of rain	1	Livestock fattening (zero-grazing)	1
Water management	1	Livestock diversity	1
Bunding	4	Transhumance	1
Ridges and bunds	1	Fodder and forage production	1
Crop focused practices		**Soil focused practices**	
Crop diversification	5	Conservation/minimum/no tillage	6
Cover cropping/mixed cropping/intercropping	11	Erosion control	1
Drought resilient crop varieties	9	Soil fertility management and soil testing	2
Crop rotation	9	Soil and water conservation	5
Improved legumes/crop varieties	7	Mulching	5
Row planting/spacing	3	**Tree focused practices**	
Early maturing varieties	3	Agroforestry	8
Pest resistant crops	2	Tree planting	2
Strip/alley farming	1	Farmer-managed natural regeneration	2
Residue focused practices		**Pest and fertilizer focused practices**	
Composting	5	Use of mineral/appropriate fertilizers	3
Organic manure	6	(Inorganic) fertilizer use	2
Efficient/green manure	6	Using ash against attacks	1
No burning/improved crop residue management	2	Integrated pest management	3
Residue incorporation	1	Micro-dosing	1
Seed focused practices		**Information focused practices**	
Reduction in seed density	1	Climate information services	4
High number of seeds per pocket & thinning	1	Belonging to farm organization	1
Certified/improved seeds	2	Information sharing	2
Seed banking	2	Change cultivation calendar	3
Combined practices		**Sloped land practices**	
Conservation agriculture (CA)	5	Contour farming	1
Organic farming	1	Terraces	1

Source: see Supplementary Table 2 for a full list of the articles.

of educational level, gender, age and household size have been researched in eight to twelve studies, the overall influence of these personal factors on CSA adoption remains diverse and complex, with contrasting outcomes.

Gender has a mixed effect on the adoption of CSA. Four studies found that male farmers are more likely to adopt different CSA practices than female farmers. Three studies find mixed effects, claiming that it depends on the CSA practices in question. One study found that male farmers are less likely to adopt water management techniques than female farmers. Similarly, age also has a mixed effect on the adoption of CSA. In this case, five studies found a negative relation (younger farmers are more likely to adopt), and three studies found a positive relation (older farmers are more likely to adopt) between age and CSA adoption. In addition, two studies found mixed effects. The same is observed for household size. Five studies found a positive link (larger households are more likely to adopt) whereas four studies found a negative link (smaller households are more likely to adopt), and one study found mixed results. Lastly, marital status was discussed in two articles, one found a positive effect meaning that married farmers are more likely to adopt certain CSA practices. The other study found mixed effects depending on the CSA practice. Based on these findings, it is challenging to definitively determine the factors that positively or negatively influence CSA. The outcomes appear to be

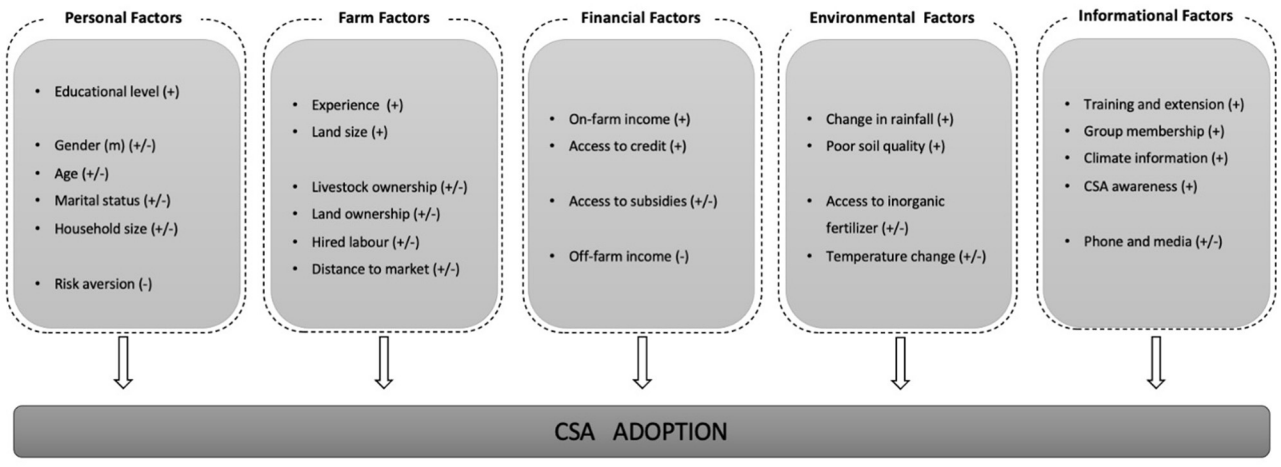

FIGURE 3
Framework of factors influencing CSA adoption. Source: authors' compilation based on 21 articles. The sign between brackets gives the general effect of that factor on CSA adoption.

contingent on various factors, including specific CSA practices and other influencing variables.

Educational level on the other hand has a predominately positive effect on the adoption of CSA. Eight studies found a positive effect, two studies found a negative effect, and two studies found mixed results. A positive effect means that higher-educated farmers are more likely to adopt CSA than less-educated farmers. Lastly, more risk-averse farmers are less likely to adopt CSA. This suggests that farmers who try to avoid risks are less willing to adopt CSA. This has been confirmed in two recent studies.

3.3.2 Farm factors

Farmers' experience, land ownership, size of farmland, and livestock ownership all have a predominantly positive effect on the adoption of CSA. Regarding the effect of farmers' experience, five studies found a positive effect, two studies found a negative effect, and one study found mixed effects. In general, farmers with more experience (years as a farmer) are more likely to adopt CSA. The impact of land ownership is discussed in four articles, two found positive effects (farmers who own more land are more likely to adopt) and the other two found mixed effects. Similarly, farmers who own livestock are more likely to adopt CSA, this was confirmed in three studies. One study found a negative effect, and another found a mixed effect. Lastly, the size of farmland has a positive effect on CSA adoption. Nine studies found a positive effect, three studies found a negative effect and one study found mixed effects. This implies that farmers with larger land holdings are more inclined to adopt CSA.

The impact of having hired labor to help on the farm or the distance from the farm to the town or market is indecisive. Regarding having hired labor to help on the farm, two studies found mixed results, suggesting that it depends on the CSA practices. Similarly, the distance from the farm to the town or market yielded mixed results. Three studies found mixed results, two studies found a negative relationship (greater distance from market/town increases farmer's likelihood of CSA adoption), and one study found a positive relationship (proximity to market/town increases farmer's likelihood of CSA adoption). Therefore, it is not possible to make an unequivocal statement on the impact of these factors on CSA adoption.

3.3.3 Financial factors

Income derived from farming activities and farmers' access to credit have a positive effect on the adoption of CSA. Four studies found that the more income farmers derived from their farming activities, the more likely they are to adopt CSA. Similarly, the more access to credit a farmer has, the more likely it is that they would adopt CSA practices. This is confirmed in six studies. Nevertheless, one study found a negative relationship (less access to credit results in more CSA adoption) and another study found mixed results.

Off-farm income on the other hand has a negative effect on the adoption of CSA. The more income a farmer makes from other activities, the less likely he or she would adopt CSA. This negative relation is confirmed by four studies, but one study found a positive effect (more off-farm income results in more CSA adoption) and a last study found mixed results. In addition, three studies included access to subsidies or government assistance as a variable in their research and found mixed results. It might be counterintuitive, but subsidies or government assistance can increase or decrease the adoption of CSA depending on the specific practices.

3.3.4 Environmental factors

The effect of environmental factors is discussed less frequently in the 21 articles. Still, overall can be observed that changes in rainfall patterns as well as changes in temperature and droughts have a positive impact on the adoption of CSA. Three studies

demonstrate how changes in rainfall patterns encourage farmers to adopt CSA practices. Similarly, changing temperatures and droughts also result in more adoption of CSA as is confirmed in three studies. Two other studies found mixed effects. In addition, when farmers struggle with poor soil quality, they are more likely to adopt CSA practices as demonstrated by two studies.

Lastly, the effect of access to inorganic fertilizer on the adoption of CSA has been studied in two articles that found contradicting results. According to one study, access to inorganic fertilizer has a negative effect on the adoption of conservation agriculture (CA) whereas the other study found a positive effect on the adoption of organic manure and minimum/no tillage. However, minimum/no tillage is one of the three principles within CA.

3.3.5 Informational factors

The informational factors such as training or access to extension, group memberships, having a phone or access to media, climate information and CSA awareness, all have a predominantly positive effect on the adoption of multiple CSA practices. Eleven studies found that training or access to extension services increases the probability that farmers adopt CSA practices. Still, three studies found mixed results and indicate that it depends on the CSA practice. Being a member of a (farm) group also has a positive effect on CSA adoption (members of a group are more likely to adopt CSA), as has been demonstrated by five studies.

The impact of having access to a phone or the media on the adoption of CSA is more debated in research. Three studies found a positive effect (access to a phone results in more CSA adoption), two studies found a negative effect (access to a phone results in less CSA adoption), and the other two studies found mixed effects. This may indicate that it strongly depends on the CSA practice.

Next, having access to climate information has been proven to increase the probability of farmers adopting CSA. Eleven studies demonstrate this relationship and two studies found mixed effects. Lastly, awareness of CSA positively influences CSA adoption as revealed in two studies. This means that providing farmers with information about the climate and CSA, will increase CSA adoption. Information is key.

4 Discussion

Research shows that some factors have very mixed effects on the adoption of CSA. This variability may suggest the influence of additional variables or dependence on the specific CSA practice. Given the detailed nature of such considerations, this review's discussion section will concentrate on elements or factors with a less debated effect. Specifically, the focus of this discussion lies on factors where an unequivocal positive or negative association has been identified in at least two-thirds of the studies. Moreover, also three factors with nuanced or mixed results are discussed.

The subsequent subsection will explore the influence of these factors on CSA adoption, as discussed by the authors across the 21 articles. However, before delving into factor-specific discussions, two general observations warrant mention. First, an analysis of factors studied over different years revealed no significant disparities regarding which factors are research over the years. Personal factors were consistently examined, peaking in 2021 where all five studies included in this systematic review addressed multiple personal factors; however, exploration was more limited in 2022. Informational and farm-related factors showed consistent examination without notable variations over time, while financial factors also received consistent consideration, albeit to a slightly lesser extent in 2021. Conversely, environmental factors were the least explored, with only one or two studies including them annually at most. A second observation entails that many studies provided only marginal explanations of their results, constraining the depth of this discussion. Consequently, the analysis is confined by the information presented in these 21 papers, and in some instances, the lack of detailed explanations hampers further elaboration in the review.

4.1 Educational level

The educational level of farmers emerges as a key determinant influencing the adoption of CSA, with a range of explanations provided by researchers. Higher-educated farmers exhibit a greater propensity to adopt CSA practices, attributed to farmers' capacity to obtain, process, and utilize information relevant to agricultural practices (Makate et al., 2019a; Abegunde et al., 2020; Obi and Maya, 2021; Oyawole et al., 2021; Sisay et al., 2023). Belay et al. (2022) found that a 1-year increase in education results in a 21.40% increase in the likelihood of adopting CSA practices. Additionally, CSA often requires substantial financial investments, which is something that more educated farmers can afford since they are more likely to possess diverse income sources (Kangogo et al., 2021). However, it is noteworthy that while higher education increases awareness and adoption of certain practices, it can also decrease adoption in other CSA practices, suggesting nuanced relationships between education and adoption outcomes (Ouédraogo et al., 2019). This is also concluded by Mthethwa et al. (2022), who suggest that educational levels may hinder CSA adoption, but they offer limited clarity or explanation regarding their observed outcomes.

4.2 Risk aversion

Farmers' risk attitude significantly influences the adoption of CSA practices, as revealed Kangogo et al. (2021) and Musyoki et al. (2022). Notably, risk-averse farmers exhibit a lower likelihood of adopting CSA technologies such as terraces, ridges, and bunds, which may involve investments in terms of labor, time, and tools. This reluctance stems from their aversion to financial risks and the unwillingness to deplete limited cash reserves on these practices (Musyoki et al., 2022). On the other hand, risk-taking farmers are more likely to adopt various CSA practices, indicating their propensity to engage in new and innovative strategies. For instance, Kangogo et al. (2021) suggest that risk-taking plays a crucial role in decisions related to irrigation and changes in cultivation calendars, highlighting the importance of farmers' risk attitudes in shaping the landscape of CSA adoption.

4.3 Farming experience

Farming experience has been found to positively influence CSA adoption. Research by Belay et al. (2022) revealed that a 1-year increase in farming experience corresponds to a 3.90% rise in the likelihood of adopting CSA practices. More experienced farmers exhibit a higher likelihood of adopting CSA practices due to heightened awareness and a better understanding of changes in farming practices. This experiential advantage enables them to identify and comprehend the changes associated with CSA more easily (Ouédraogo et al., 2019). Additionally, the positive relationship between farming experience and CSA adoption is attributed to more efficient engagement with extension services and stronger social networks, providing these farmers with enhanced support systems (Abegunde et al., 2020). However, contrasting findings indicate that less experienced farmers may be more inclined to adopt specific technologies, such as weather-smart technology, possibly driven by a desire to mitigate risks in the absence of extensive experience (Antwi-Agyei and Amanor, 2023).

4.4 Farmland size

Farmers' land size is a critical factor influencing the adoption of CSA practices, as revealed by various studies. Makate et al. (2019a) and Sisay et al. (2023) explain that farmers with more extensive landholdings are more willing to apply CSA technologies since they have more space and flexibility to experiment and implement practices like agroforestry, integrated soil fertility management, and conservation agriculture. Moreover, wealthier households often have larger land sizes and higher asset indices, making it more feasible to adopt CSA practices such as stress-tolerant livestock, terraces, integrated soil fertility management, composting, stone bunds, farmer-managed natural regeneration, improved crop varieties, and fodder and forage production, as they possess the resources to manage associated risks (Zampaligré and Fuchs, 2019; Musyoki et al., 2022; Sisay et al., 2023). However, some researchers found mixed results, implying that the relationship between farmers' land size and CSA adoption depends on the practices. For instance, the positive association between land size and soil testing aligns with the scale advantage larger landowners have. In contrast, the negative association with intercropping suggests that farmers with smaller land sizes are more involved in crop diversification, probably to meet household food needs (Kangogo et al., 2021).

4.5 On-farm income

The impact of farmers' on-farm income on the adoption of CSA is mostly positive. Studies consistently show a positive and significant effect of (annual) on-farm income on the use of various CSA technologies, including conservation agriculture, agroforestry, climate information services, and more. This relationship is attributed to farmers with higher incomes being able to afford inputs and equipment required for implementing these technologies (Sisay et al., 2023). Moreover, more farm income reduces risk aversion and enhances exposure to information (Abegunde et al., 2020). In addition, this relationship between on-farm income and CSA adoption also has to do with selling agricultural produce for income generation, indicating that farmers engaged in commercial farming are more likely to adopt CSA practices. In contrast, those primarily cultivating for household consumption or with alternative income sources outside farming exhibit lower CSA adoption rates (Mthethwa et al., 2022).

4.6 Off-farm income

The impact of farmers' off-farm income on the adoption of CSA practices reveals multifaceted dynamics. Abegunde et al. (2020), Djido et al. (2022), and Musyoki et al. (2022) found that average monthly off-farm income had a statistically significant and negative influence on CSA adoption, suggesting that reliance on off-farm activities as major income sources diminishes the commitment to agricultural production. This weak commitment is reflected in the reduced likelihood of adopting various CSA practices, as diversifying income sources may lead farmers to perceive less need for enhancing agricultural resilience through CSA adoption. Furthermore, cultivating a diversified income portfolio empowers smallholder farmers who are heavily reliant on agriculture for their livelihoods to mitigate the impacts of climate-related risks. This strategy is recognized as a crucial approach to enhancing farmers' resilience against climatic shocks (Djido et al., 2022). In contrast, Kurgat et al. (2020) noted a positive association between off-farm income and livestock diversity, emphasizing the role of financial resources in acquiring inputs for livestock production and the potential for larger land areas to cultivate diverse feeds, reducing reliance on purchased feeds.

4.7 Access to credit

Access to credit emerges as an important factor influencing the adoption of CSA practices in the reviewed studies. The positive and significant impact of credit access is evident in the adoption of multiple CSA practices such as conservation agriculture and integrated soil fertility management (Zampaligré and Fuchs, 2019; Kangogo et al., 2021; Sisay et al., 2023). According to Kangogo et al. (2021) and Sisay et al. (2023) this can be explained because having access to credit enhances farmers' financial capabilities, empowering them to cover transaction, equipment, and input costs linked to the diverse CSA technologies they may choose to adopt. Moreover, more access to cash empowers households to withstand and recover from losses resulting from climate change (Zampaligré and Fuchs, 2019). For instance, farmers with access to credit show a 20% higher likelihood of adopting climate information services, aligning with the understanding that CSA practices often involve substantial initial investments, and credit accessibility facilitates acquiring inputs (Ouédraogo et al., 2019).

4.8 Change in rainfall patterns

The changing patterns of rainfall also seem to impact the adoption of CSA among smallholder farmers. On the one hand, in case of less rainfall or droughts, empirical results find a positive relationship with CSA adoption. When there is variability in rainfall amounts, farmers are compelled to actively seek diverse practices to conserve and harvest water, particularly during water-shortage seasons, thereby relying on CSA practices to ensure water access and management in response to shortages (Mthethwa et al., 2022). For instance, drought conditions positively influence the decision to implement ridges and bunds, as these structures mitigate surface run-off. The reduced run-off enhances soil moisture retention, providing farmers with a valuable resource during dry spells, and facilitating crop cultivation (Musyoki et al., 2022). On the other hand, an abundance of rainfall resulting in floods also impacts CSA adoption. Research shows that farmers who experience floods, are more likely to adopt stress-tolerant livestock and fertilizer application. The faith in stress-tolerant livestock's ability to cope with flooding, coupled with the desire to enhance farmland productivity after floods, motivates farmers to adopt these practices (Musyoki et al., 2022).

4.9 Soil quality

Soil quality is another factor influencing the adoption of CSA practices. According to Pangapanga-Phiri and Mungatana (2021) farmers with poor soil quality are more likely to adopt CSA practices such as soil and water conservation. Similarly, Teklu et al. (2023) found that poor soil fertility positively influences the adoption of agroforestry, row planting, and improved crop varieties with 4.7, 4.3, and 5% respectively. Neither of the researchers further explains this relationship.

4.10 Training or access to extension officers

Access to training emerges as a crucial determinant positively influencing the adoption of CSA practices among farmers. Various studies consistently demonstrate the significant and favorable impact of training on the utilization of diverse CSA technologies, such as conservation agriculture, agroforestry, integrated soil fertility management, terraces, integrated pest management, crop diversification, and more (Musyoki et al., 2022; Sisay et al., 2023). The findings underscore that farmers with access to training are more adept at employing CSA practices compared to those without such access. Specific training interventions are highlighted as influential factors in the adoption of particular technologies. For instance, training on variety selection positively influences the adoption of intercropping, and drought-tolerant or improved crop varieties whereas training on climate information services significantly promotes the adoption of such services (Ouédraogo et al., 2019).

Training is intertwined with farmers' access to extension services, which is also a pivotal factor influencing the adoption of CSA. Studies consistently affirm the positive and significant impact of extension contacts on various CSA technologies. Contact with extension services is associated with a heightened awareness of specific practices and technical support, which results in farmers being better informed and ready to implement drought-tolerant or improved crop varieties, integrated soil fertility management, micro-dosing practices, agroforestry, and organic manure adoption (Ouédraogo et al., 2019; Zakaria et al., 2020; Oyawole et al., 2021; Sisay et al., 2023). The multifaceted role of extension services encompasses providing information on climate change, adaptation, resilience, and agricultural management practices, contributing to increased awareness and adoption of CSA practices (Abegunde et al., 2020).

4.11 Group membership

Belonging to agricultural-related associations or groups emerges as a key determinant positively influencing the adoption of CSA practices among farmers. The evidence across various studies consistently underscores the significant and positive impact of group membership on CSA adoption such as changing the cultivation calendar, certified seed adoption, crop rotation, and soil testing (Kangogo et al., 2021). Membership in these associations helps build strong social networks, fosters social capital, provides farmers with access to public spheres and creates platforms for the exchange of experiences and challenges. Such interactions within agricultural groups not only contribute to enlightenment but also offer practical advice on coping with agricultural problems, thereby enhancing CSA adoption (Abegunde et al., 2020; Belay et al., 2022). Furthermore, these groups enable farmers to exchange information about accessing agricultural-related innovations, services, training, and knowledge on new technologies, while also providing opportunities to obtain key inputs necessary for implementing CSA practices (Zampaligré and Fuchs, 2019).

4.12 Climate information

Access to climate information is another crucial factor significantly influencing the adoption of CSA. Farmers equipped with reliable information on current and future temperature, rainfall, and climate conditions demonstrate a higher propensity to adopt CSA practices, including conservation agriculture, agroforestry, and crop diversification (Moutouama et al., 2022; Sisay et al., 2023). Information can be shared and received in various ways such as farm groups, extension services, mobile-based platforms, and community displays (Obi and Maya, 2021; Mujeyi et al., 2022). Moreover, access to weather forecasts can come from scientific sources or indigenous knowledge systems (Mujeyi et al., 2022). Access to climate information can be linked to a 20.20% increase in the likelihood of adopting selected CSA practices (Belay et al., 2022). This information enables farmers to adjust their farming activities and strengthen their resilience in response to climate change (Zampaligré and Fuchs, 2019).

4.13 CSA awareness

The last factor to be discussed is closely related to the previous factor, climate information. Research shows that also awareness of CSA practices is a major determinant of CSA adoption. Therefore, a primary obstacle to the adoption of CSA is a lack of awareness about the practice. In the context of CSA, having sufficient awareness and appropriate information is crucial for the decision to embrace a new technology. A substantial portion of the population is not familiar with these practices (Moutouama et al., 2022). Teklu et al. (2023) found that farmers who are aware of CSA are between 6.70 and 33% more likely to adopt CSA practices such as improved crop varieties, agroforestry, crop residue management, compost, row planting, soil and water conservation. Only for crop rotation they did not find a significant effect, this might be because crop rotation is also used by farmers who are not so familiar with CSA. Both articles do not provide further information explaining their findings.

4.14 Factors with nuanced effects

In this section, factors exhibiting nuanced effects on the adoption of CSA practices are explored, showcasing how these relationships can be influenced by various contextual factors. The decision to narrow the focus to three factors with mixed results was driven by their recurring presence in the reviewed studies, indicating their prominence in the literature on CSA adoption.

First, "gender" emerges as a factor with mixed results even though the conventional assumption suggests a higher readiness for CSA adoption among male farmers. In some publication this is confirmed. For instance, Pangapanga-Phiri and Mungatana (2021) discovered that female farmers, often hindered by limited access to agricultural inputs, exhibit lower technical efficiency, posing challenges to their adoption of CSA practices. This finding was corroborated by studies from Kangogo et al. (2021) and Musyoki et al. (2022), which highlighted gendered disparities in resource access and information, contributing to lower CSA adoption rates among female farmers. On the other hand, Musyoki et al. (2022) found that female farmers tend to adopt more individual CSA practices, while male farmers are more inclined to combine multiple practices, potentially due to their superior resource access. Interestingly, Oyawole et al. (2021) reported contrasting results, indicating that female farmers adopt more CSA practices than their male counterparts, particularly in agroforestry, green manure, organic/compost use, and zero/minimum tillage. This diversity underscores the complex interplay between gender dynamics, resource availability, and CSA practices.

Secondly, the influence of "age" on the adoption of CSA practices presents a nuanced picture with varied outcomes. Older farmers, presumed to possess greater experience and access to resources, are expected to exhibit higher CSA adoption rates. Studies by Zampaligré and Fuchs (2019), Kurgat et al. (2020), and Sisay et al. (2023) support this notion, highlighting the propensity of older farmers to adopt certain CSA practices such as stone bunds and crop diversification. This inclination may stem from their economic stability and larger land holdings, facilitating access to improved crop varieties and enabling the adoption of labor-intensive techniques. However, the age of farmers also exerts a negative impact on the adoption of innovative technologies. Younger farmers, characterized by greater adaptability and access to information, demonstrate higher adoption rates for practices such as pest-resistant crops, conservation agriculture, and drought-tolerant varieties. Obi and Maya (2021) note a diminishing likelihood of older farmers embracing new farming practices because they are more risk-adverse, further highlighting the generational disparity in CSA adoption. Consequently, while older farmers may leverage their experience and resources to adopt certain CSA practices, younger farmers exhibit a greater propensity for embracing novel and technology-driven approaches to agricultural sustainability.

Thirdly, the variable "distance to market" presents a nuanced relationship with CSA adoption, contrary to the initial expectation of many researchers of a negative impact. Makate et al. (2019a) highlighted the higher transaction costs associated with increased distance to markets, potentially discouraging CSA adoption due to difficulties in accessing input and output markets. Similarly, Abegunde et al. (2020) emphasized how distance from towns or markets affects farmers' access to crucial resources such as information, technologies, and credit facilities, while also increasing transportation costs and complicating monitoring efforts for distant farmland. Zakaria et al. (2020) reported both negative and positive effects of distance on CSA adoption, with some practices like adopting drought-tolerance varieties and adjusting planting periods positively influenced by distance to market or town, yet others, such as adopting early-maturing varieties, bunding, and irrigation, are negatively impacted. This inconsistency could stem from the challenges smallholder farmers face in accessing extension services when located far from markets. Surprisingly, Makate et al. (2019b) found a positive association between distance to market and the adoption of improved legume varieties, potentially attributed to extensive advertising and community seedbanks mitigating the negative impact of distance. Additionally, Musyoki et al. (2022) discovered a positive influence of distance to market on household decisions to adopt fertilizer, possibly due to collaboration with local NGOs facilitating doorstep delivery of farm inputs, bypassing the need for market visits.

Although there are other factors with nuanced effects (e.g., farmers' marital status, household size, livestock ownership, hired labor, access to a phone and media, and more), these three factors already demonstrate the complexity of the relationship between context and CSA adoption, highlighting the multifaceted considerations that influence farmers' decisions in adopting sustainable agricultural practices in SSA.

5 Conclusion

This review navigates the complex landscape of CSA adoption among African farmers. Originating as an integrated response to climate change, food security, and greenhouse gas emissions, CSA was introduced by the FAO and is supported by numerous international organizations. Despite promising research results, CSA is not being adopted on a large scale by farmers in developing countries and is thus not achieving its full potential (Westermann

et al., 2018). Research demonstrates that certain socioeconomic factors, such as gender, age, asset ownership, education, and farm size amongst others, can be associated with the adoption and use of CSA practices in smallholder farming (Makate et al., 2018). Yet, the effect of these factors on CSA adoption remains ambiguous.

Previously, there was a tendency to view the factors influencing CSA adoption as either having a positive or negative effect, but it is often more complex and nuanced than such a binary perspective suggests. In this review study, 21 articles were analyzed to better understand the influencing factors and their effects on CSA adoption and one can conclude that the story is more nuanced. First and foremost, there are almost no factors with an unequivocal effect on CSA adoption. For instance, although one might anticipate a positive impact of subsidies or government assistance on CSA adoption, three studies reported mixed effects. This implies that such support can also negatively influence the adoption of specific CSA practices. These mixt effects or contradicting results from different studies about the effect of certain factors on CSA adoption might be partly attributed to the abundance of practices falling under the CSA umbrella, practices with different purposes and thus applied in different situations. In these 21 articles alone, over 50 distinct CSA practices were identified.

Secondly, the factors influencing CSA adoption can be grouped into five categories: personal, farm, financial, environmental, and informational categories. The personal (e.g., gender, educational level, age, marital status, household size, and risk attitude) and farm factors (e.g., experience, land ownership, farmland size, livestock ownership, hired labor, and distance to market/town) have mainly mixed effects whereas informational factors (e.g., training and extension, group membership, phone access, climate information, and CSA awareness) have predominantly a positive effect on CSA adoption. Still, educational level, farmers' experience, and farmland size emerged as factors positively impacting CSA adoption. Financial factors (e.g., on-farm income, off-farm income, credit access, and subsidies or government assistance) exhibited clearer patterns, with income from farming and access to credit fostering adoption, while off-farm income hindered adoption. Environmental factors (e.g., inorganic fertilizer access, change in rainfall, change in temperature, and soil quality) indicated positive impacts related to changes in rainfall patterns, temperature, and droughts. Informational factors consistently played a positive role, emphasizing the importance of training, access to extension, group memberships, climate information, and CSA awareness. Nevertheless, the articles addressing these factors lack detailed discussions on the modalities of information dissemination or the quality of training and extension programs.

A third conclusion that can be drawn is the lack of consideration of environmental factors in these studies. Where personal factors are researched in various articles (each factor is often studied in eight to 10 articles), environmental factors are only discussed in two to four articles. In addition, there are other environmental factors such as changes in biodiversity, bushfires, or desertification, that are not discussed in any of the 21 articles. This can be partly explained because environmental factors are more challenging to measure through surveys or interviews. Moreover, it might also be attributed to the keywords used for this systematic review.

This brings us to this studies' limitations. It is crucial to acknowledge that the choice of keywords significantly influences systematic reviews, potentially omitting studies that could also be relevant. The focus on English articles might introduce language bias, and stringent critical appraisal criteria may exclude pertinent studies. Moreover, some studies presented multiple models, this review specifically relied on the information derived from the model identified by the authors as the best-fitting model. Additionally, while certain studies explored data from two or more regions separately and collectively, this review only utilized the pooled data since it is not possible to take regional differences into account in this review paper. However, one should acknowledge that differences exist between regions. Lastly, the diverse nature of CSA practices complicates clear distinctions and the generalization of findings.

Besides these conclusions and limitations, some general recommendations for policymakers and practitioners can be made. The critical role of information and training in CSA adoption suggests an imperative to enhance its dissemination. How this should be done effectively and efficiently, does require further research. Moreover, it is important to take into account personal and farm factors and acknowledge how they might influence the implementation of CSA projects or practices. The reviewed articles show that the effect of certain factors can have unexpected results on CSA adoption. In addition, caution is warranted when promoting CSA practices, acknowledging the complexity of factors and the need for tailor-made approaches. In addition, subsidies and government assistance, while potential catalysts, may hinder the adoption of certain CSA practices, necessitating careful consideration of contextual nuances.

Data availability statement

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

Author contributions

MF: Conceptualization, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. SVS: Writing – review & editing. JC: Writing – review & editing. SVP: Conceptualization, Supervision, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

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

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frevc.2024.1356335/full#supplementary-material

References

Abegunde, V., Sibanda, M., and Obi, A. (2020). Determinants of the adoption of climate-smart agricultural practices by small-scale farming households in King Cetshwayo district municipality, South Africa. *Sustainability* 12:195. doi: 10.3390/su12010195

African Development Bank (2019). *Analysis of Adaptation Components of Africa's Nationally Determined Contributions (NDCs)* (Côte d'Ivoire).

Alexander, S. (2019). What climate-smart agriculture means to members of the Global Alliance for climate-smart agriculture. *Fut. Food* 7, 21–30. doi: 10.17170/kobra-2018122073

Anderson, T. (2021). Why 'climate-smart agriculture' isn't all it's cracked up to be. *Guardian*.

Antwi-Agyei, P., and Amanor, K. (2023). Typologies and drivers of the adoption of climate smart agricultural practices by smallholder farmers in rural Ghana. *Curr. Res. Environ. Sustain.* 5:100223. doi: 10.1016/j.crsust.2023.100223

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., and Cattaneo, A. (2013). Adoption and intensity of adoption of conservation farming practices in Zambia. *Agric. Ecosyst. Environ.* 187, 72–86. doi: 10.1016/j.agee.2013.08.017

Belay, A., Oludhe, C., Mirzabaev, A., Recha, J., Berhane, Z., Osano, P., et al. (2022). Knowledge of climate change and adaptation by smallholder farmers: evidence from southern Ethiopia. *Heliyon*. 8:e12089. doi: 10.1016/j.heliyon.2022.e12089

Brown, B., Nuberg, I., and Llewellyn, R. (2017). Stepwise frameworks for understanding the utilisation of conservation agriculture in Africa. *Agric. Syst.* 153, 11–22. doi: 10.1016/j.agsy.2017.01.012

Chandra, A., McNamara, K. E., and Dargusch, P. (2018). Climate-smart agriculture: perspectives and framings. *Clim. Policy* 18, 526–541. doi: 10.1080/14693062.2017.1316968

CIDSE (2015). *Climate-Smart Revolution... or a New Era of Green-Washing?* International Cooperation for Development and Solidarity. Available online at: https://www.cidse.org/wp-content/uploads/2015/05/753_751_750_CIDSE_GACSA_briefing_FINAL.pdf (accessed November 28, 2023).

Climate Smart Agricultural Concerns (2015). *Don't Be Fooled! Civil Socity Says No To "Climate Smart Agriculture"*. CIDES: together for global justice. Available online at: https://www.iatp.org/sites/default/files/2015_09_17_GACSA%20statement%20FINAL.pdf (accessed December 4, 2023).

de Oca, M., Munguia, O., Pannell, D., and Llewellyn, R. (2021). Understanding the adoption of innovations in agriculture: a review of selected conceptual models. *Agronomy* 11, 1–20. doi: 10.3390/agronomy11010139

Djido, A., Zougmor,é, R., Houessionon, P., Ouédraogo, I., and Diouf, N. (2022). To what extent do weather and climate information services drive the adoption of climate-smart agriculture practices in Ghana? *Clim. Risk Manag.* 32:100309. doi: 10.1016/j.crm.2021.100309

FAO (2013). *Climate-Smart Agriculture Sourcebook*. Rome: FAO.

FAO (2023). *Climate Change*. Food and Agriculture Organization of the United Nations. Available olnine at: https://www.fao.org/climate-change/en#:$\sim$:text=Climate%20change%20has%20both%20direct,and%20disease%20and%20ocean%20acidification (accessed December 11, 2023).

Global Plan of Action (2022). *But What Is Unsustainable Agriculture?* Global Plan of Action. Available olnine at: http://www.globalplanofaction.org/unsustainable.html (accessed March 28, 2022).

Gupta, S., Rajiah, P., Middlebrooks, E., Baruah, D., Carter, B., Burton, K., et al. (2018). Systematic review of the literature: best practices. *Acad. Radiol.* 25, 1481–1490. doi: 10.1016/j.acra.2018.04.025

Haddaway, N., Macura, B., Whaley, P., and Pullin, A. (2017). *ROSES Flow dIagram for Systematic Maps. Version 1.0.* Available olnine at: https://www.roses-reporting.com/flow-diagram (accessed November 27, 2023).

Kangogo, D., Dentoni, D., and Bijman, J. (2021). Adoption of climate-smart agriculture among smallholder farmers: does farmer entrepreneurship matter? *Land Use Policy* 109:105666. doi: 10.1016/j.landusepol.2021.105666

Karlsson, L., Naess, L. O., Nightingale, A., and Thompson, J. (2018). 'Triple wins' or 'triple faults'? Analysing the equity implications of policy discourses on climate-smart agriculture (CSA). *J. Peas. Stud.* 45, 150–174. doi: 10.1080/03066150.2017.1351433

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., and Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy* 42, 400–411. doi: 10.1016/j.landusepol.2014.08.016

Kiptot, E., Hebinck, P., Franzel, S., and Richards, P. (2007). Adopters, testers or pseudo-adopters? Dynamics of the use of improved tree fallows by farmers in western Kenya. *Agric. Syst.* 94, 509–519. doi: 10.1016/j.agsy.2007.01.002

Kurgat, B., Lamanna, C., Kimaro, A., Namoi, N., Manda, L., and Rosenstock, T. (2020). Adoption of climate-smart agriculture technologies in Tanzania. *Front. Sustain. Food Syst.* 4:55. doi: 10.3389/fsufs.2020.00055

Lipper, L., Thornton, P., Campell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., et al. (2014). Climate-smart agriculture for food security. *Nat. Clim. Changr* 4, 1068–1071. doi: 10.1038/nclimate2437

Lipper, L., and Zilberman, D. (2018). "A short history of the evolution of the climate smart agriculture approach and its links to climate change and sustainable agriculture debates," in *Climate Smart Agriculture Building Resilience to Climate Change*, eds L. Lipper, N. McCarthy, D. Zilberman, S. Asfaw, and G. Branca (Rome: FAO and Springer), 13–31.

Long, T., Blok, V., and Poldner, K. (2017). Business models for maximising the diffusion of technological innovations for climate-smart agriculture. *Int. Food Agribus. Manag. Rev.* 20, 5–23. doi: 10.22434/IFAMR2016.0081

Makate, C., Makate, M., and Mango, N. (2018). Farm household typology and adoption of climate-smart agriculture practices in smallholder farming systems of southern Africa. *Afr. J. Sci. Technol. Innovat. Dev.* 10, 421–439. doi: 10.1080/20421338.2018.1471027

Makate, C., Makate, M., Mango, N., and Siziba, S. (2019a). Increasing resilience of smallholder farmers to climate change through multiple adoption of proven climate-smart agriculture innovations. Lessons from Southern Africa. *J. Environ. Manag.* 231:69. doi: 10.1016/j.jenvman.2018.10.069

Makate, C., Makate, M., Mutenje, M., Mango, N., and Siziba, S. (2019b). Synergistic impacts of agricultural credit and extension on adoption of climate-smart agricultural technologies in southern Africa. *Environ. Dev.* 32:100458. doi: 10.1016/j.envdev.2019.100458

Mann, W., Lipper, L., Tennigkeit, T., McCarthy, N., Branca, G., and Paustian, K. (2009). *Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies*. Rome: FAO.

Matthews, J. R. (2017). Understanding indigenous innovation in rural West Africa: challenges to diffusion of innovations theory and current social innovation practice. *J. Hum. Dev. Capabil.* 18, 223–238. doi: 10.1080/19452829.2016.1270917

McCarthy, N., Lipper, L., and Branca, G. (2011). *Climate Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation*. Rome: Mitigation of Climate Change in Agriculture (MICCA), Working paper.

Meijer, S., Catacutan, D., Ajayi, O., Sileshi, G., and Nieuwenhuis, M. (2015). The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. *Int. J. Agric. Sustain.* 13, 40–54. doi: 10.1080/14735903.2014.912493

Mlenga, D., and Maseko, S. (2015). Factors influencing adoption of conservation agriculture: a case for increasing resilience to climate change and variability in Swaziland. *J. Environ. Earth Sci.* 5, 16–25.

Moutouama, F., Tepa-Yotto, G., Agboton, C., Gbaguidi, B., Sekabira, H., and Tamò, M. (2022). Farmers' perception of climate change and climate-smart agriculture in Northern Benin, West Africa. *Agronomy* 12:1348. doi: 10.3390/agronomy12061348

Mthethwa, K., Ngidi, M., Ojo, T., and Hlatshwayo, S. (2022). The determinants of adoption and intensity of climate-smart agricultural practices among smallholder maize farmers. *Sustainaility* 14:16926. doi: 10.3390/su142416926

Mujeyi, A., Mudhara, M., and Mutenje, M. (2022). Adoption patterns of Climate-Smart Agriculture in integrated crop-livestock smallholder farming systems of Zimbabwe. *Clim. Dev.* 14:1930507. doi: 10.1080/17565529.2021.1930507

Musyoki, M., Busienei, J., Gathiaka, J., and Karuku, G. (2022). Linking farmers' risk attitudes, livelihood diversification and adoption of climate smart agriculture technologies in the Nyando basin, South-Western Kenya. *Heliyon* 8:e09305. doi: 10.1016/j.heliyon.2022.e09305

Neufeldt, H., Jahn, M., Campbell, B. M., Bedding, J., DeClerck, F., De Pinto, A., et al. (2013). Beyond climate-smart agriculture: toward safe operating spaces for global food systems. *Agric. Food Sec.* 2, 1–6. doi: 10.1186/2048-7010-2-12

Nyasimi, M., Amwata, D., Hove, L., Kinyangi, J., and Wamukoya, G. (2014). *Evidence of Impact: Climate-Smart Agriculture in Africa*. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Obi, A., and Maya, O. (2021). Innovative climate-smart agriculture (CSA) practices in the smallholder farming system of South Africa. *Sustainability* 13:126848. doi: 10.3390/su13126848

OECD-FAO (2016). *Agriculture in Sub-Saharan Africa: Prospects and Challenges for the Next Decade*. Paris: OECD Publishing.

Ogunyiola, A., Gardezi, M., and Vij, S. (2022). Smallholder farmers' engagement with climate smart agriculture in Africa: role of local knowledge and upscaling. *Clim. Policy* 22, 411–426. doi: 10.1080/14693062.2021.2023451

Omotoso, A., Letsoalo, S., Olagunju, K., Tshwene, C., and Omotayo, A. (2023). Climate change and variability in sub-Saharan Africa: a systematic review of trends and impacts on agriculture. *J. Clean. Prod.* 414:137487. doi: 10.1016/j.jclepro.2023.137487

Ouédraogo, M., Houessionon, P., Zougmoré, R., and Partey, S. (2019). Uptake of climate-smart agricultural technologies and practices: actual and potential adoption rates in the climate-smart village site of Mali. *Sustainability* 11:174710. doi: 10.3390/su11174710

Oyawole, F., Shittu, A., Kehinde, M., Ogunnaike, G., and Akinjobi, L. (2021). Women empowerment and adoption of climate-smart agricultural practices in Nigeria. *Afr. J. Econ. Manag. Stud.* 12, 105–119. doi: 10.1108/AJEMS-04-2020-0137

Pangapanga-Phiri, I., and Mungatana, E. (2021). Adoption of climate-smart agricultural practices and their influence on the technical efficiency of maize production under extreme weather events. *Int. J. Disast. Risk Reduct.* 61:102322. doi: 10.1016/j.ijdrr.2021.102322

Rosenstock, T., Lamanna, C., Chesterman, S., Bell, P., Arslan, A., Richards, M., et al. (2016). *The Scientific Basis of Climate-Smart Agriculture: A Systematic Review Protocol*. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

ROSES (2023). *Home*. RepOrting Standards for Systematic Evidence Syntheses. Available online at: https://www.roses-reporting.com/#:\sim:text=ROSES%20helps%20to%20raise%20standards,steps%20in%20the%20review%20process (accessed November 15, 2023).

Sisay, T., Tesfaye, K., Ketema, M., Dechassa, N., and Getnet, M. (2023). Climate-smart agriculture technologies and determinants of farmers' adoption decisions in the Great Rift Valley of Ethiopia. *Sustainability* 15:43471. doi: 10.3390/su15043471

Sono, D., Wei, Y., and Jin, Y. (2021). Assessing the climate resilience of sub-saharan Africa (SSA): a metric-based approach. *Land* 10, 1–23. doi: 10.3390/land10111205

Stevenson, J., Vanlauwe, B., Macours, K., Johnson, N., Krishnan, L., Place, F., et al. (2019). Farmer adoption of plot-and farm-level natural resource management practices: between rhetoric and reality. *Glob. Food Sec.* 20, 101–104. doi: 10.1016/j.gfs.2019.01.003

Taylor, M. (2018). Climate-smart agriculture: what is it good for? *J. Peasant Stud.* 45, 89–107. doi: 10.1080/03066150.2017.1312355

Tegart, W., Sheldon, G., and Griffiths, D. (1990). *Climate Change: Working Group II Impacts Assessment of Climate Change*. Canberra, ACT: Australian Government Publishing Service.

Teklu, A., Simane, B., and Bezabih, M. (2023). Multiple adoption of climate-smart agriculture innovation for agricultural sustainability: empirical evidence from the Upper Blue Nile Highlands of Ethiopia. *Clim. Risk Manag.* 39:100477. doi: 10.1016/j.crm.2023.100477

Uman, L. (2011). Systematic reviews and meta-analyses. *J. Can. Acad. Child Adolesc. Psychiatry* 20, 57–59.

UN/DESA (2021). *UN/DESA Policy Brief #105: Circular Agriculture for Sustainable Rural Development*. Available online at: https://www.un.org/development/desa/dpad/publication/un-desa-policy-brief-105-circular-agriculture-for-sustainable-rural-development/ (accessed October 8, 2021).

United Nations (2021). *World Population Prospects 2019*. UN. Available online at: https://population.un.org/wpp/Graphs/Probabilistic/POP/TOT/947 (accessed December 4, 2023).

Westermann, O., Förch, W., Thornton, P., Körner, J., Cramer, L., and Campbell, B. (2018). Scaling up agricultural interventions: case studies of climate-smart agriculture. *Agric. Syst.* 165, 283–293. doi: 10.1016/j.agsy.2018.07.007

World Bank (2011). *Missing food: The Case of Postharvest Grain Losses in SSA*. Washington, DC: The International Bank for Reconstruction and Development/The World Bank.

World Bank (2018). *Scaling Up Climate-Smart Agriculture through the Africa Climate Business Plan*. Washington, DC: World Bank.

World Bank (2023). *Climate Smart Agriculture Investment Plans: Bringing CSA to Life*. Available online at: https://www.worldbank.org/en/topic/agriculture/publication/climate-smart-agriculture-investment-plans-bringing-climate-smart-agriculture-to-life (accessed November 16, 2023).

Zakaria, A., Azumah, S., Appiah-Twumasi, M., and Dagunga, G. (2020). Adoption of climate-smart agricultural practices among farm households in Ghana: the role of farmer participation in training programmes. *Technol. Soc.* 63:101338. doi: 10.1016/j.techsoc.2020.101338

Zampaligré, N., and Fuchs, L. (2019). Determinants of adoption of multiple climate-smart adaptation practices in sudano-sahelian pastoral and agro-pastoral production systems. *Sustainability* 11:184831. doi: 10.3390/su11184831