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Drivers of farmers' adaptive behavior to climate change: The 3F-SEC framework

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ABSTRACT

Climate change can have a negative impact on agriculture and lead to significant crop losses and increasing food insecurity. Despite the growing body of research on farmers' adaptive behaviors to climate change, there remains a lack of comprehensive classification of influencing factors. In our systematic literature review comprising 87 articles, we identified 179 distinct drivers, categorized into socio-demographic characteristics, farm attributes, financial resources, situational influences, experiential aspects, and cognitive elements. Notably, cognitive drivers, such as beliefs about climate change consequences, were frequently cited (348 times), along with critical socio-demographic factors like age and education. Drawing from a case study of farmers in central Colombia, we illustrate how these factors interact. Through the lens of four exemplary farmer types, we observe that older farmers were less likely to adapt due to limited exposure to climate emergencies and higher age, whereas for others community relationships drove adaptive behaviors. High-income motivated adaptation, while direct experience with climate disasters increased adaptation willingness. Finally, the framework we have developed highlights the importance of understanding the complex interplay of different factors behind farmers' adaptation decisions, paving the way for the development of more localized and context-specific climate adaptation strategies.

1. Introduction

Climate change impacts include rising global temperatures, more frequent and severe extreme weather events, disruption of ecosystems and biodiversity, and challenges to water and food security. Nonetheless, it is necessary to recognize that these effects are not uniformly manifested globally (Epanchin-Niell et al., 2017), and may vary within the same geographical region (A. K. Gupta et al., 2020). Consequently, there is a certain level of uncertainty in determining how the different communities will be specifically impacted (Jacoby et al., 2015). One of the main groups expected to be affected by climate change is farmers, especially in "developing" countries, as their economies are largely dependent on the agricultural sector (Asmare et al., 2019; de Sousa et al., 2018). For this reason, it is important to understand how farmers respond to these effects, bearing in mind that everyone may experience them differently.

Different problems associated with climate, such as changes in average temperatures, changes in weather patterns, and changes in seasons, have a direct impact on agricultural production (Gerlitz et al., 2017; Liu et al., 2022; Mulwa et al., 2016). Several studies have been conducted to show the consequences of climate change on different types of crops; and a negative correlation has been found between these climate disruptions and crop yields (Arshad et al., 2017; Chen et al., 2016; Hertel et al., 2010; Miller et al., 2021; Quaye et al., 2018). These reductions in agricultural production directly affect farmers' livelihoods, specifically their food security and income (Abid et al., 2016; Narayanan and Sahu, 2016; Wang et al., 2022). Likewise, due to international trade in agricultural products, it is expected that these local problems could have repercussions at the global level (Baldos et al., 2019).

Climate change creates pressure on farming operations and farmers are expected to adapt their practices in these scenarios of climate uncertainty. However, for a farmer to be seen as adapting, two things are needed: they must notice changes in the environment they are used to,

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and then make changes to their farming to deal with these changes (Deressa et al., 2011; Talanow et al., 2021). Many of the practices that farmers adopt are options that are already available to them, such as planting new crops; others may be more drastic, such as finding other jobs (Mulwa et al., 2016). However, in many cases, farmers need practices that rely on institutions to make them available, like heat-resistant seeds and new infrastructure (Wineman and Crawford, 2017).

Understanding the decision-making process of farmers about the adaptation measures they need on their farms is crucial for understanding adaptation success. The more severe the climate fluctuations, the greater the effects on agricultural production, so adaptation measures to mitigate these impacts will be more necessary (Asmare et al., 2019). The adaptive capacity of farmers depends not only on their available resources and assets but also on their experience with the climate and how their cognitive processes are being affected by these new environmental changes (Adger, 2003). Therefore, if farmer behavior is to be studied, it is recommended to incorporate geographic, economic, institutional, and socio-demographic characteristics, as well as characteristics of their farming operations (Castro Campos, 2022; Duffy et al., 2021). Incorporating these different dimensions into the study of adaptive behavior allows for a deeper understanding of farmers' actions in the face of climate change.

In recent years, there has been an increase in research on the behavior and decisions of farmers in relation to their adaptation to climate change. However, to the best of our knowledge, a systematic analysis of all the different types of drivers of farmers' adaptive behavior has not yet been carried out. Previous studies, such as Lyle (2015), proposed a nested multi-scale spatial hierarchy of factors influencing climate change adaptation but did not incorporate other categories, particularly situational factors like institutional and market drivers. Van Valkengoed and Steg (2019) examined motivational factors of climate change but were limited to only thirteen factors. Dessart et al. (2019) focused on factors that affect the adoption of new agricultural practices; yet the scope of this study was on the adoption of sustainable agricultural practices rather than climate change mitigation within farms. Similarly, Sok et al. (2021) reviewed farmer behavior through the Theory of Planned Behavior but did not distinguish whether these behaviors were influenced by climate change.

In contrast, some research has systematically analyzed literature related to climate change, but these studies have been limited to particular topics. For instance, Wiederkehr et al. (2018) focused solely on migration as an adaptation strategy, while Soubry et al. (2020) examined farmers' perceptions of climate change. Ricart et al. (2022) studied disparities between farmers' climate perceptions and meteorological data and Feola et al. (2015) looked at cases of adaptation to climate change without systematically organizing the factors involved. We find that these studies, although important, do not incorporate all the dimensions that influence farmers' adaptive behavior to climate change. This represents a significant knowledge gap. Therefore, a comprehensive literature review is necessary to incorporate all the factors influencing the adaptive behavior of farmers to climate change.

The objective of this study is to improve the understanding of the behavior of farmers when making decisions that allow them to adapt to climate change by systematically analyzing all the different factors that affect the decision-making process. This study aims to address the following research questions: (1) What are the drivers influencing farmers' decision-making behavior regarding climate change adaptation measures? (2) How do these influential factors interact with each other and shape individuals' adaptive behaviors? By investigating these questions, this study seeks profound insights into understanding how agricultural stakeholders respond and adjust strategies accordingly.

To accomplish these objectives, we conduct a review of 87 articles that examine farmers' adaptive behavior in response to climate change. The study utilizes the Scientific Procedures and Rationale for Systematic Literature Reviews (SPAR-4-SLR) protocol proposed by Paul et al. (2021) and applied by Castro Campos (2022) and Castro Campos and Qi (2024). As a result, we introduce the Farmer-Farm-Financial-Situational-Experiential-Cognitive (3F-SEC) framework, which provides a holistic overview of all the factors that drive farmers' adaptive behavior in response to climate change. This framework makes contributions to the existing literature in three ways. Firstly, it is the first study to categorize all the drivers of adaptive behavior based on their nature and type; secondly, it integrates various drivers that have not been collectively addressed in previous studies; lastly, it serves as a resource for future research endeavors aimed at investigating farmer behavior under changing climatic conditions.

The present article is structured in the following manner. Section 2 outlines the research methodology used, specifically the implementation of the SPAR-4-SLR protocol, explaining how articles are obtained, categorized, and assessed. Section 3 presents the bibliographic results derived from these gathered articles, introduces the 3F-SEC framework, and a sub-section for the discussion of the results. Continuing to section 4, the 3F-SEC framework is applied in a case study involving farmers in central Colombia who have faced and responded to challenges associated with climate change. Finally, concluding remarks can be found in section 5.

2. Methodology

A systematic literature review is a valuable method for effectively managing a wide range of knowledge within a specific academic domain. The primary objective of this method is to integrate, synthesize, and critically analyze findings from previous studies to provide a comprehensive understanding of the chosen research topic. Doing so, not only offers insights into existing knowledge but also helps identify gaps that require further investigation. Furthermore, a key aim is to develop new theoretical frameworks by building upon the foundational insights derived from prior research (Castro Campos, 2022; Paul and Criado, 2020; Snyder, 2019; Tranfield et al., 2003).

The methodology employed in this study follows the SPAR-4-SLR protocol proposed by Paul et al. (2021), which provides a structured approach with clear guidelines for each stage of the review process. This protocol ensures a systematic and organized method for identifying, selecting, and analyzing relevant literature. It encompasses three major stages: assembling, arranging, and assessing. Each stage is further divided into six sub-stages, including identification, acquisition, organization, purification, evaluation, and reporting (Fig. 1). By emphasizing comprehensive coverage, the SPAR-4-SLR protocol systematically assembles, arranges, and assesses literature, thereby providing a clear structure of the analysis and traceability of the results. In addition, we employ an inductive coding procedure based on Corbin and Strauss (2014), which allowed us to identify all drivers of farmers' adaptive behavior towards climate change based on the selected articles. The list of all the articles included and the codes and framework used in their systematization can be found in supplement S1 "List of Articles".

Assembling	Identification Domain: Farmers' behavior in adapting to climate change Research Question: What are the drivers of farmers' adaptive behavior to climate change? Source type: Journal articles Source Quality: Literature from Web of Science (WOS). ↓ Acquisition Search mechanism and material acquisition (n = 146) 1. WOS for literature in English: (n = 145) 2. WOS for literature in Portuguese: (n = 1) Search period: 2008–2022 Search keywords in WOS: (Climate change OR Climate variability OR climatic change) AND (Farmers OR rural households) AND (Behavior OR Behaviour) AND (Adaptation OR resilience OR adoption OR coping) AND (Vulnerability) (n = 146) ↓
Arranging	**Organization** **Organizing codes:** year, journal, citations, country, theory,

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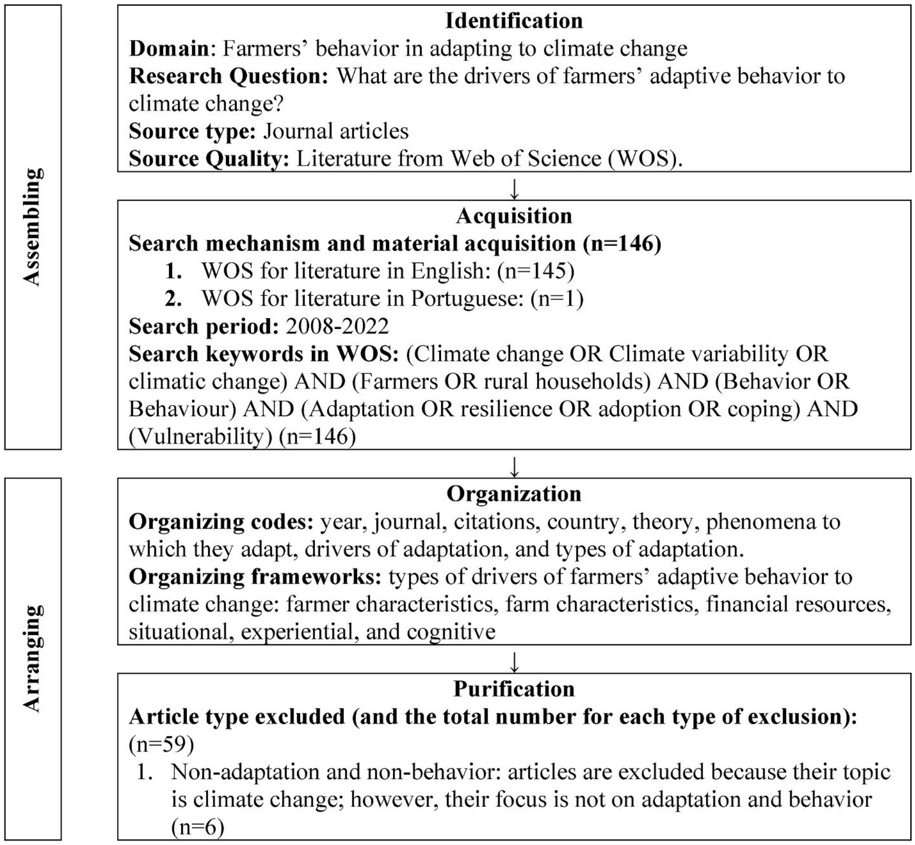

Fig. 1. Flowchart of the SPAR-4 SLR protocol.

(*continued*)

phenomena to which they adapt, drivers of adaptation, and types of adaptation.
Organizing frameworks: types of drivers of farmers' adaptive behavior to climate change: farmer characteristics, farm characteristics, financial resources, situational, experiential, and cognitive
↓
Purification
Article type excluded (and the total number for each type of exclusion): (n = 59)
1. Non-adaptation and non-behavior: articles are excluded because their topic is climate change; however, their focus is not on adaptation and behavior (n = 6)
2. Non-adaptation and behavior: articles are excluded because the topic is about behavior as a consequence of climate change; however, the focus is not adaptation (n = 1)
3. Non-adaptation: articles are excluded because their topic is climate, but the focus is not adaptation (n = 1)
4. Adaptation and non-behavior: articles are excluded because the studies do not explain the behavior of the farmers (n = 28)
5. Non-climate change: articles are excluded because the adaptation behavior studied is not related to climate change (n = 13)
6. Non-agricultural: articles are excluded because the unit studied is not farm (n = 7)
7. Literature reviews (n = 3)
Article type included (and the total number of articles included): (n=87)
This classification is made according to the different categories of drivers of adaptive behavior (organizing framework) that the authors included in their research. These can be found in detail in supplement S2 "Heat Map", where the proportion by type of drivers that the authors used in their studies can be observed.
1. Six different types of drivers of adaptive behavior: Asrari et al. (2022); Azadi et al. (2019a); Budhathoki et al. (2020); Elijah and Odiyo (2020); Guo et al. (2021); W. Li et al., 2021; Lone et al. (2022); Mu et al. (2020); Puupponen et al. (2022); Roesch-McNally et al.

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(*continued*)

(2017); Savari and Shokati Amghani (2021); Shi et al. (2019); Skevas et al. (2022); Wens et al. (2022); Zobeidi et al. (2021) (n = 15)
2. Five different types of drivers of adaptive behavior: Abbas et al. (2022); Albert et al. (2021); Aliabadi et al. (2022); Arifah et al. (2022); Azadi et al. (2019b); Below et al. (2012); Benabderrazik et al. (2022); Burnham and Ma (2017); de Matos Carlos et al. (2020); Dieye and Roy (2012); Do and Ho (2022); Engler et al. (2021); Islam et al. (2021); Linder and Campbell-Arvai (2021); Li et al. (2017); Li et al. (2022); Masud et al. (2017); Messmer et al. (2021); Minh et al. (2020); Mirzaei et al. (2022); Pakmehr et al. (2020); Quiroga et al. (2020); Saroar and Routray (2012); Tetteh et al. (2020); Wale et al. (2022) (n = 25)
3. Four different types of drivers of adaptive behavior: Ayal et al. (2021); Buelow and Cradock-Henry (2018); Bulla and Steelman (2016); Campos et al. (2014); Gebrehiwot and van der Veen (2015); Goli et al. (2022); Guo et al. (2022); Jellason et al. (2020); Kirsch and Filipi (2018); Lamichhane et al. (2022); Mohammadzadeh et al. (2021); Muench et al. (2021); Niles et al. (2015); Ntim-Amo et al. (2022); Nyantakyi-Frimpong et al. (2022); Petersen-Rockney (2022); Petrescu-Mag et al. (2022); Poudyal et al. (2021); Rodríguez-Cruz and Niles (2021); Tessema et al. (2019); Van Aelst and Holvoet (2018); Zheng and Byg (2014); Zobeidi et al. (2016) (n = 23)
4. Three different types of drivers of adaptive behavior: Bagagnan et al. (2019); Brondizio and Moran (2008); Ciampi et al. (2022); Haden et al. (2012); Hailegiorgis et al. (2018); Lei et al. (2016); Neisi et al. (2020); Pauw (2013); Peng et al. (2022); Running et al. (2019); Singh et al. (2017); Tomlinson and Rhiney (2018); Wang et al. (2013) (n = 13)
5. Two different types of drivers of adaptive behavior: Arbuckle et al. (2015); Delfiyan et al. (2021); Fiorella et al. (2021); Gilbert and McLeman (2010); Keshavarz and Karami (2016); Ndlovu (2019); Orduño Torres et al. (2020) (n = 7)
6. One type of driver of adaptive behavior: Fujisawa and Kobayashi (2011); Rao et al. (2020); van Duinen et al. (2015); Yin et al. (2020) (n = 4)
↓

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2. Non-adaptation and behavior: articles are excluded because the topic is about behavior as a consequence of climate change; however, the focus is not adaptation (n=1)
3. Non-adaptation: articles are excluded because their topic is climate, but the focus is not adaptation (n=1)
4. Adaptation and non-behavior: articles are excluded because the studies do not explain the behavior of the farmers (n= 28)
5. Non-climate change: articles are excluded because the adaptation behavior studied is not related to climate change (n=13)
6. Non-agricultural: articles are excluded because the unit studied is not farm (n=7)
7. Literature reviews (n=3)

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3. **Four different types of drivers of adaptive behavior:** Ayal et al., (2021); Buelow and Cradock-Henry (2018); Bulla and Steelman (2016); Campos et al. (2014); Gebrehiwot and van der Veen (2015); Goli et al. (2022); H. Guo et al. (2022); Jellason et al. (2020); Kirsch and Filipi (2018); Lamichhane et al. (2022); Mohammadzadeh et al. (2021); Muench et al. (2021); Niles et al. (2015); Ntim-Amo et al. (2022); Nyantakyi-Frimpong et al. (2022); Petersen-Rockney (2022); Petrescu-Mag et al. (2022); Poudyal et al. (2021); Rodríguez-Cruz and Niles (2021); Tessema et al. (2019); Van Aelst and Holvoet (2018); Zheng and Byg (2014); Zobeidi et al. (2016) (n=23)

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Fig. 1. (*continued*).

(*continued*)

Assessing	**Evaluation** **Analysis method:** Content analysis on the drivers of adaptive behavior **Agenda proposal method:** A holistic understanding of the drivers that influence farmers' adaptive behavior to climate change ↓ **Reporting** **Reporting conventions:** Graphs, frequency tables, heat map, 3F-SEC framework **Limitation(s):** Only WOS articles were analyzed. **Source(s) of support:** Financial support from the German Academic Exchange Service (DAAD) under the program Development-Related Postgraduate Courses (EPOS), contract number P1401273

2.1. Assembling

In the assembling stage, we proceed with two sub-stages: identification and acquisition. During the identification process, we determine the research domain, refine our research question, and evaluate both the type of sources and their quality. Specifically for this study, only scholarly articles published are deemed suitable for inclusion. To ensure a comprehensive scope of literature review relevant to our topic, all articles in the WOS database are considered. Next is the acquisition sub-

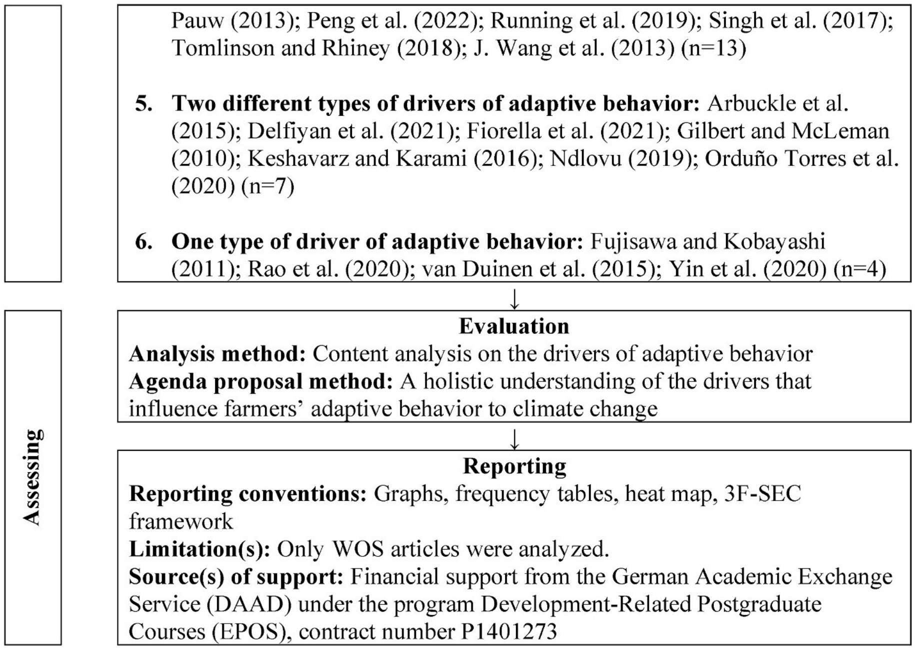

Fig. 1. (*continued*).

stage, which includes the acquisition mechanism, search period, keywords, and total number of articles.

To conduct a comprehensive systematic literature review addressing our research questions, it was essential to select keywords that capture the nature of this research. Moreover, to ensure the robustness and reliability of our results, we used a search equation to encompass a broad and complex spectrum of relevant studies (see Fig. 1, Acquisition). This includes a breakdown of the search terms and Boolean operators applied. The search equation is grounded in the definition of climate change provided by the Intergovernmental Panel on Climate Change (IPCC, 2014), which states, “Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer” (p. 120). This definition shows the importance of examining long-term changes in climate patterns and their impacts, thereby justifying the inclusion of terms like “climate change”, “climate variability”, and “climatic change” in our search equation.

There is no consensus on the definition of behavior, as it varies depending on the field of study (Carman and Zint, 2020; Henriques and Michalski, 2020; Uher, 2016). However, a simple definition according to the American Psychological Association (n. d.) behavior is “an organism's activities in response to external or internal stimuli, including objectively observable activities, introspectively observable activities, and nonconscious processes”. Given that the focus of our study is adaptive behavior to climate change, we complement this definition with the four principles of behavior proposed by Baum (2013): (a) only living organisms behave, (b) has a purpose, (c) takes time and, (d) involves choice. These principles help frame our research on how farmers' behaviors are directed toward adaptation to climate change impacts, emphasizing the intentional and choice-based nature of such adaptations. Similarly, building on the definition of behavior, we have systematically examined how different types of factors trigger adaptive responses in farmers, facilitating the categorization of these drivers. Additionally, we draw inspiration from the work of Castro Campos (2022), Dessart et al. (2019), and Lyle (2015) in operationalizing the components of behavior.

The inclusion of terms like “adaptation,” “resilience,” “adoption,” and “coping” is theoretically grounded in understanding the spectrum of responses that farmers may employ in the face of climate threats and based on the definition proposed by the IPCC (2014) as “the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects” (p. 118). Furthermore, the terms “farmers” and “rural households” were included to specifically target the population of interest. Finally, adding “vulnerability” was done to include the possibility of studies where it is measured using adaptive capacity (Alam, 2017; Baca et al., 2014; M. Gupta et al., 2020). Using these specific search terms in conjunction with Boolean operators, as shown in Fig. 1, we found 146 relevant academic articles. The range of years for the articles chosen for this study emerged organically from the literature and was not predetermined by us.

2.2. *Arranging*

This stage consists of two sub-stages: organization and purification. For the organization sub-stage, we use various organizing codes: year, journal, citations, country, theory, crop/livestock, drivers of adaptive behavior, and types of adaptation to climate change (as outlined in supplement S1 “List of Articles”). Given that the objective of this literature review is to examine the determinants of adaptive behavior, we implement a framework based on different types of drivers (including socio-demographic characteristics of farmers, farm characteristics, financial resources (incorporating the different forms of capital), situational factors, experiential aspects, and cognitive factors). These categories are further disaggregated by type and driver in supplement S3 “Drivers of Adaptive Behavior”.

In the purification sub-stage, we select and exclude articles based on their alignment with our research focus, which aims to investigate farmers' adaptive behavior towards climate change. Specifically, any articles that did not directly address this topic are excluded from further analysis. The excluded articles amount to 59 in total, while 87 articles meet the criteria for inclusion and proceed to the next stage of analysis. A more comprehensive overview of this purification process is provided in Fig. 1, which lists the excluded articles, the main reasons for exclusion, and the selected articles (see also Supplement S2 “Heat Map” for an overview of the selected articles.

2.3. Assessing

Within this stage, evaluation and reporting are sub-stages. In the evaluation sub-stage, we apply content analysis techniques based on Krippendorff (2004) and Schreier (2014) to investigate the various factors that drive adaptive behavior among farmers, as well as their impact on farmers' overall intentions to adapt. For the coding, we followed the methodological steps outlined by Corbin and Strauss (2014). Firstly, we used an open coding approach to systematically identify all the different behavioral drivers, recognizing 179 in total. Subsequently, we employed axial coding to categorize the individual codes into broader groups that encompass similar drivers. Finally, all the drivers were categorized into six different types: socio-demographic characteristics, farm-specific attributes, financial resources, situational influences, experiential aspects, and cognitive elements (see supplement S3 "Drivers of Adaptive Behavior"). On the other hand, the reporting sub-stage encompasses all the graphical representations used to outline all the significant findings. Additionally, it addresses any limitations of the literature review and includes acknowledgment of funding sources related to this research (see Fig. 1).

3. Results

3.1. Main dataset information

Over the years, there has been a significant increase in studies looking at how farmers adapt to climate change (Fig. 2). Particularly in recent times, approximately 58% of the 87 reviewed articles were published between 2020 and 2022. Geographically, a significant proportion of research sites are situated in Asian and African countries (42 and 21, respectively), as depicted in Fig. 3. Among these locations, Iran is identified as having conducted the most studies, with 14 in total (e.g. Delfiyan et al., 2021; Goli et al., 2022; Pakmehr et al., 2020). China is the country with the second-highest number of investigations carried out with 11 articles (e.g. Burnham and Ma, 2017; Guo et al., 2021; Mu et al., 2020; Peng et al., 2022). The United States has ranked third in terms of the number of studies conducted with a total of eight (e.g. Bulla and Steelman, 2016; Haden et al., 2012; Petersen-Rockney, 2022). In contrast, the continent with the least investigations is Oceania with only one study being undertaken in New Zealand (see Niles et al., 2015).

Among the articles examined, only 37 articles identified particular phenomena to which the farmers were adapting, naming 16 different phenomena (Table 1). The most frequently analyzed topic was water-related in some capacity and its effects on agricultural systems. Drought appeared as a single phenomenon in 17 articles (e.g. Neisi et al., 2020; Savari and Shokati Amghani, 2021; Wens et al., 2022) and in conjunction with other phenomena in three more (see Brondizio and Moran, 2008; Petersen-Rockney, 2022; Zheng and Byg, 2014). Water availability was discussed in five articles (e.g. Haden et al., 2012; Pakmehr et al., 2020), meanwhile, floods were mentioned in six (e.g. Ntim-Amo et al., 2022; Nyantakyi-Frimpong et al., 2022; Skevas et al., 2022).

Other less common issues explored include different climate change scenarios and investigate how farmers would adapt accordingly (e.g. Hailegiorgis et al., 2018; Roesch-McNally et al., 2017), and hurricanes (e.g. Rodríguez-Cruz and Niles, 2021). Additionally, some articles investigate adaptations to various phenomena, these include changes in temperature, cold spells, droughts, floods, water availability, hailstorms, etc. (e.g. Budhathoki et al., 2020; Minh et al., 2020; Mohammadzadeh et al., 2021).

Only a fraction of the studies included in this literature review –specifically 34 out of 87– incorporated a theoretical framework in their research designs. Table 2 presents the 18 theories identified in these studies. The majority of these theories focus on understanding the drivers behind individuals' adoption of specific behaviors, particularly in response to threats. They typically include assessments of attitudes, beliefs, intentions, and stages of change. Among these, Protection Motivation Theory (PMT) was the most widely used, featured in 16 articles (e.g. Delfiyan et al., 2021; Engler et al., 2021; Neisi et al., 2020). The second most frequently used theory was the Theory of Planned Behavior, used in four (e.g. W. Li et al., 2021; Linder and Campbell-Arvai, 2021). The other theories within this group were each mentioned in only one article: the Trans-Theoretical Stage Model (TTM) theory in Gebrehiwot and van der Veen (2015), the Reasoned Action Approach in Roesch-McNally et al. (2017), the Health Belief Model (HBM) in Zobeidi et al. (2021), and the Protective Action Decision Model (PADM) in Ntim-Amo et al. (2022).

The second group of theories also focuses on factors that affect adaptive behaviors. However, these theories primarily examine how individuals or communities respond to environmental changes, particularly climate change. The Values–Beliefs–Norms (VBN) theory was used in two articles (see Arbuckle et al., 2015; Peng et al., 2022), and incorporated into pro-environmental behaviors. Another theory used is the Model of Private Proactive Adaptation to Climate Change (MPPACC), which extends the PMT and was used in a single article by Burnham and Ma (2017). The other theories in this group were each used only once: Liebig's Law of the Minimum in Niles et al. (2015), and Social Risk Management in Zheng and Byg (2014).

Grounded Theory was used in two articles (see Arifah et al., 2022; Petersen-Rockney, 2022) and focuses on developing theories grounded in data systematically gathered and analyzed. The other theories were each used in only one article. Some of these theories relate to psychological and cognitive processes, such as the Construal Level Theory in Rodríguez-Cruz and Niles (2021), the Psychological Distance Theory in

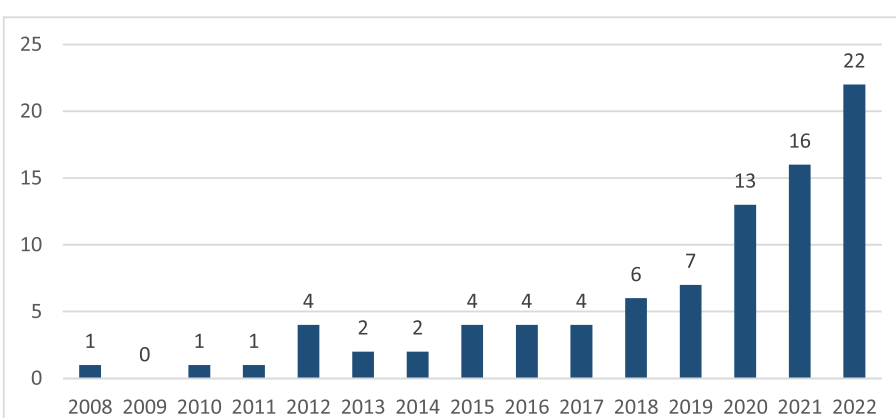

Fig. 2. Year of publication.
Source: Authors based on the systematic literature review (Supplement S1).

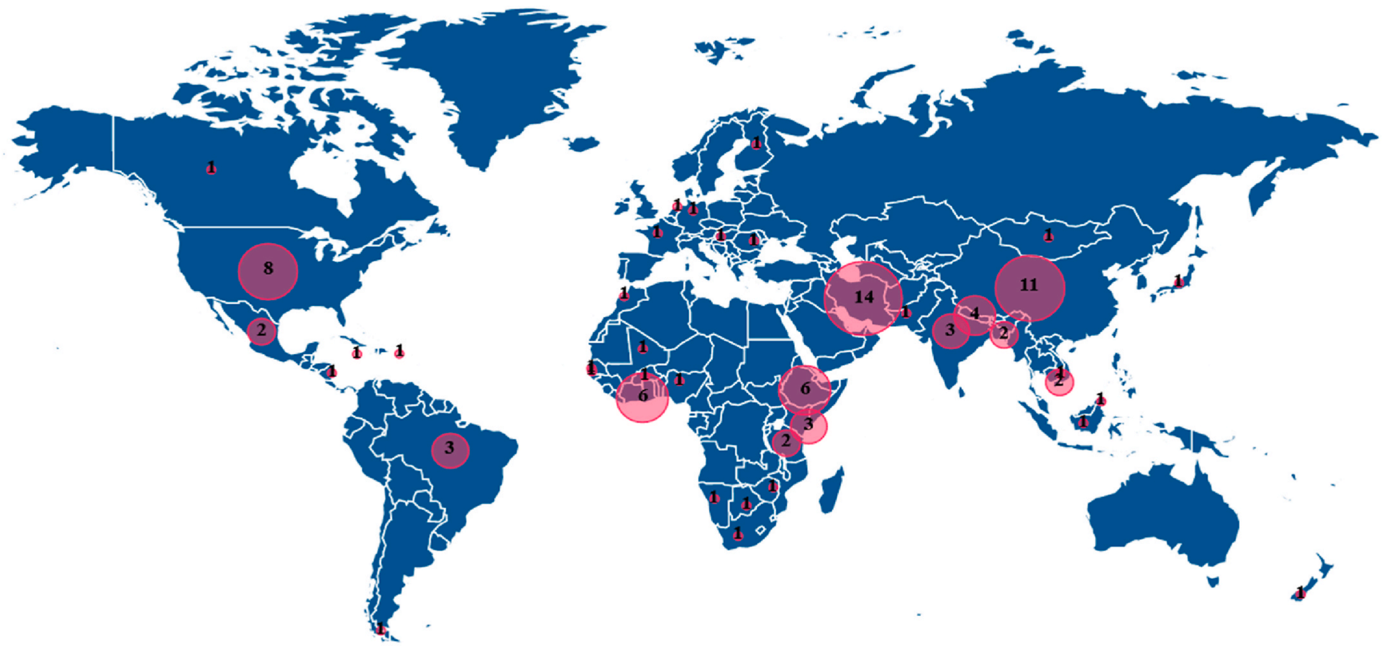

Fig. 3. Research locations.
Source: Authors based on the systematic literature review (Supplement S1).

Table 1
Phenomenon to which farmers adapt.

The phenomenon to which farmers adapt	Frequency
Drought	20
Floods	6
Water Availability	5
Changes in Temperature	4
Hurricane	3
Cold Spells	2
Climate Change Scenario	2
Sea-level Rise	1
Fires	1
Erratic Rains	1
Change in seasons	1
Pests	1
Hailstorms	1
Tropical depressions	1
Low precipitation	1
Heat waves	1
No specific event	50

Source: Authors based on the systematic literature review (Supplement S1)

Table 2
Theories.

Theory	Frequency
Protection Motivation Theory (PMT)	16
Theory of Planned Behavior	4
Grounded theory	2
Values–Beliefs–Norms	2
Construal Level Theory	1
Health Belief Model (HBM)	1
Liebig's Law of the Minimum	1
Model of private proactive adaptation to climate change (MPPACC)	1
Optimal Utility Theory	1
Protective Action Decision Model (PADM)	1
Psychological Dimensions of Climate Change	1
Psychological Distance Theory	1
Random Utility Maximization (RUM)	1
Reasoned Action Approach	1
Social Risk Management	1
Theory of Diffusion of Innovations	1
Trans-Theoretical Stage Model (TTM)	1
Unified Theory of Acceptance	1
Use of Technology Theory (UTAUT)	1
Without theory	53

Source: Authors based on the systematic literature review (Supplement S1).

Niles et al. (2015), and the Psychological Dimensions of Climate Change in Ayal et al. (2021). Others focus on innovation and technology adoption, including the Unified Theory of Acceptance and Use of Technology (UTAUT) by Asrari et al. (2022), and the Theory of Diffusion of Innovations in Muench et al. (2021). Finally, there were economic and utility-based models, such as Optimal Utility Theory in Minh et al. (2020) and Random Utility Maximization (RUM) in Wale et al. (2022).

We identify various strategies for adaptation and comprehensively categorize them (Table 3). These categories encompass a diverse range of practices, including techniques utilized in farming and livestock management, as well as the option of reducing or quitting farming. This information is detailed in supplement S4 "Types of Adaptation". The majority of the identified measures pertain to farming practices, with 30 distinct approaches being mentioned 302 times across the 87 articles reviewed. Within this category, the most frequently cited adaptive practices were soil conservation techniques, input management, the use of adapted or improved crops, adjustments in the timing of farming activities, and the adoption of new practices (e.g. Elijah and Odiyo, 2020; Guo et al., 2022; Quiroga et al., 2020; Rao et al., 2020; Tessema et al., 2019).

The second category with the highest number of cited adaptation types pertains to irrigation. Among these, improvements to irrigation systems were the most commonly mentioned practice, followed by having different sources of water for irrigation (e.g. Albert et al., 2021; Lone et al., 2022; Shi et al., 2019). On the other hand, increasing irrigation was the least used and was only mentioned once (see Peng et al., 2022). The categories encompassing financial, livestock, and income diversification adaptations include nine types of adaptations each, with financial adaptations being the most frequently mentioned, cited 53 times. Within this category, acquiring some type of insurance was the most common practice, and credits the second one (e.g. Benabderrazik et al., 2022; Zobeidi et al., 2021). For livestock-related adaptations, the most common practices were having livestock and selling it (e.g.

Table 3
Types of adaptive practices.

Category	Number of practices	Frequency
Farming	30	302
Irrigation	12	105
Livestock	10	45
Financial	9	53
Income diversification	9	38
Assets	8	36
Migration	8	33
Environmental oriented	8	35
Community-based	7	20
Information	5	12
Traditional practices	5	14
Business management oriented	4	9
Food security measures	4	6
Education/Extension	3	8
Reducing or quitting farming	2	7
No adaptation/maladaptation	2	9

Source: Authors based on the systematic literature review (Supplement S4).

Ndlovu, 2019; Tetteh et al., 2020). Regarding income diversification, obtaining jobs outside the agricultural sector was the most frequently cited practice (e.g. Budhathoki et al., 2020; Tomlinson and Rhiney, 2018).

The assets category includes eight types of adaptations, with 36 mentions across the articles. The most cited adaptation within this category was the sale or rent of land, followed by the purchase, hire, or improvement of technology as the second most cited (e.g. Campos et al., 2014; Lone et al., 2022). Similarly, the environmental-oriented category, also with eight types of adaptations, was mentioned 35 times, with reforestation or the management of forests being the most common practice (e.g. Muench et al., 2021) and prevention of environmental pollution the least cited from this category (see Keshavarz and Karami, 2016). Migration adaptations involve eight different practices, with migrating and temporal migration being the most common types (e.g. Pauw, 2013; Wang et al., 2013). Community-based adaptations, comprising six distinct practices, were mentioned 20 times, with community-based water management as the most prevalent adaptation (e.g. Niles et al., 2015). Traditional practices, including five types of adaptations, within this category, activities related to wild foods, religious practices, use of native species, and having traditional knowledge were each cited three times (e.g. Brondizio and Moran, 2008; Gilbert and McLeman, 2010; Jellason et al., 2020; Mohammadzadeh et al., 2021).

Business management-oriented adaptations include four different practices, the most common being changes in the business model (e.g. Skevas et al., 2022). The information-related category has three types of adaptations and focusing on weather forecast information is the most cited one (e.g. Azadi et al., 2019b). Within the education/extension adaptations category, education opportunities and the use of consultants were the most cited (e.g. Below et al., 2012; Campos et al., 2014). Eating different foods was the most common adaptation in the food security category (e.g. Van Aelst and Holvoet, 2018). Additionally, some farmers have also explored more drastic alternatives such as reducing farming operations or quitting farming altogether (e.g. Masud et al., 2017; Poudyal et al., 2021; Skevas et al., 2022). In some cases, certain farmers have been observed to consider non-action or engaging in maladaptive behavior as an option (e.g. Li et al., 2017; Mirzaei et al., 2022; Tomlinson and Rhiney, 2018; Zheng and Byg, 2014).

3.2. Drivers of adaptive behavior and the 3F-SEC framework

A total of 179 factors are identified, categorized, and classified by type (Table 4). For a more detailed review of each of the behavioral drivers, they are listed by category and type in supplement S3 "Drivers of Adaptive Behavior". This supplement includes an overview of all the drivers by article. Among these factors, cognitive elements are the most prominent drivers. These were cited 348 times, with particular attention to beliefs about the negative consequences associated with climate change (identified 65 times in the articles analyzed). The prominence of cognitive drivers highlights the significance placed on psychological processes in understanding farmers' adaptive behavior within the theoretical frameworks employed in the analyzed publications.

Table 4
Type and categories of drivers of adaptive behavior to climate change.

Type	Category	Number of drivers	Frequency
Farmer	Socio-demographics	14	183
Farmer	Household	8	45
Farm	Land	7	56
Farm	Irrigation	6	25
Farm	Livestock	3	16
Farm	Characteristics	10	82
Financial	Income and Expenses	9	67
Financial	Capital	7	68
Situational	Access	9	40
Situational	Market	4	11
Situational	Social	14	58
Situational	Information	7	30
Situational	Environment	7	43
Situational	Institutions	5	17
Experiential	Impacts of climate change	13	85
Experiential	Current adaptation practices	10	51
Experiential	Costs of adaptation	2	2
Cognitive	Risk	5	13
Cognitive	Perceptions	18	101
Cognitive	Beliefs	14	194
Cognitive	Psychological distance	4	35
Cognitive	Other	3	5

Source: Authors based on the systematic literature review (Supplement S3).

The socio-demographic characteristics of the farmers are in second place, these were referenced 183 times. Within these, the most common drivers were farmers' age and educational level (cited 54 and 51 times, respectively). These findings can be attributed to the frequent use of such variables in quantitative studies. Situational factors constitute another significant category of drivers, encompassing external elements beyond farmers' control such as markets and institutions. In total, 46 different situational factors are identified and mentioned 199 times throughout the reviewed articles. The most prevalent driver within this type was the social connections and affiliations that farmers have, which were counted 14 times.

The fourth most recurrent type of drivers counted during the research is the one related to the characteristics of the farm, which were cited 179. Within this, 26 different types of drivers were determined, where the size of the farm was the most prevailing of all (cited 28 times). Farmers' experiences are significant determinants in shaping their adaptive behavior. These were categorized according to their direct experiences with the effects of climate change, their experiences with the different adaptive practices they already employed on their farms, and the costs of adaptation. 25 drivers were identified within this type and were listed 138 times. The most common being impacts on agriculture, which was counted 24 times.

Additionally, the financial resources of farmers play a critical role in either motivating or impeding their willingness to adapt to climate change. In the reviewed articles, 16 different drivers, between farmers' income and expenses and their capital (which can be both financial and non-financial), were found. In total, these were mentioned 135 times: 68 related to capital along with 67 mentions of income and expenses. Among these, income and its different sources was the most common of all, which was cited 44 times.

Based on the analysis of the 87 articles studied and the systematization of the behavioral drivers, the 3F-SEC framework was developed (Fig. 4). This framework provides a comprehensive illustration of the various types and categories of drivers that have been identified. This

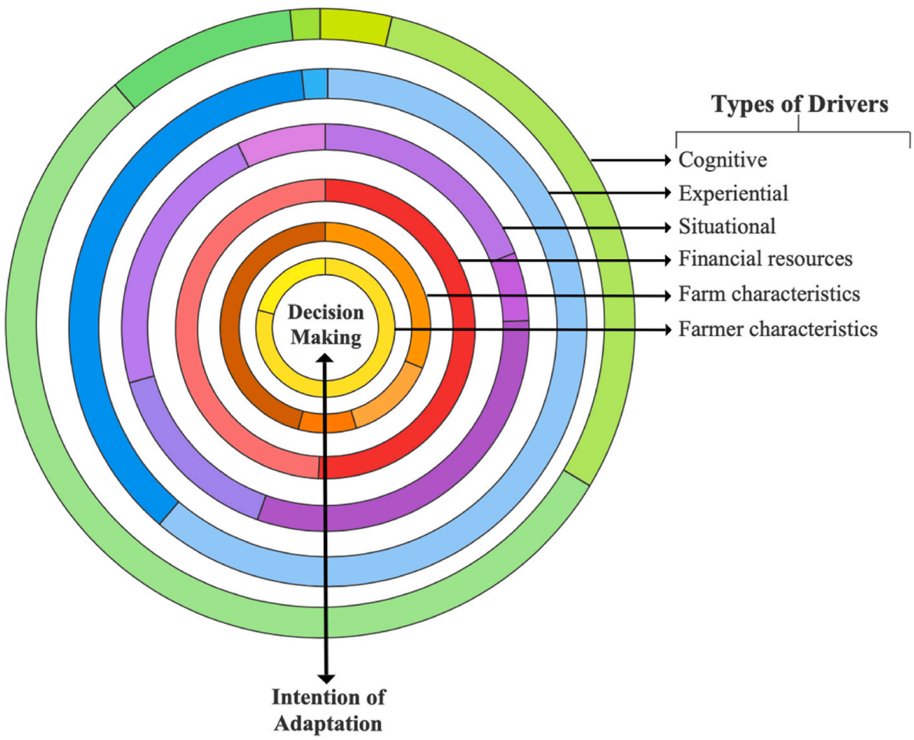

Fig. 4. 3F-SEC framework of adaptation to climate change.
Notes: Each circle represents a type of behavioral driver. These are organized starting with the most personal and easy to measure, which are the socio-demographic characteristics of farmers, and ending with the types of drivers related to the farmer's mental processes, which are the cognitive ones. However, the order in which they are organized has no particular meaning. The double arrow through all the circles represents the farmers' decision-making process to adapt to climate change. This double date means that this process is not unidirectional and involves all types of behavioral drivers. Likewise, the drivers can influence each other, so it is difficult to demonstrate any causality between them.
Source: Authors based on the systematic literature review (Supplement S3).

visual representation offers a holistic understanding of the multitude of factors that can influence a farmer's decision-making process about their intention to adapt to climate change. Each circle represents a specific type of driver, with the size of each division being proportional to its frequency in the literature review.

Each circle is divided according to the categories identified in each type of driver. Additionally, this division was made according to the frequency in which they were mentioned in the eighty-seven articles (Table 4). The first circle is divided by the socio-demographic characteristics of the farmer (80.3%) and the characteristics of the household (19.7%). The second circle is all farm components, such as land (31.3%), irrigation (14%), livestock (8.9%), and farm characteristics (45.8%). The third circle represents the farmer's financial status, income and expenses (49.6%), and capital, both monetary and non-monetary (50.4%). The fourth circle represents the situational categories, i.e. where the farmer has little or no control. Access to different things (20.1%), the market (5.5%), society (29.1%), information (15.1%), the environment (21.6%), and institutions (8.5%). The fifth circle represents all the farmers' experiences, such as the impacts of climate change (61.6%), the adaptation measures they already use (37%), and the costs of adapting (1.4%). The last circle has different cognitive processes of farmers, such as their understanding of risk (3.7%), their perceptions (29%), their beliefs (55.7%), psychological distance (10.1%), and other cognitive processes that do not belong to any of the other categories (1.4%).

The 3F-SEC framework consists at one end of the characteristics associated with farmers and their households, while at the other end lie cognitive components such as beliefs, perceptions, risks, and psychological distance. The middle section encompasses farm-related characteristics, financial resources, and experiential factors, as well as situational elements over which farmers may have limited control including access to resources or institutions and market conditions. While Fig. 4 provides a visual representation of how the circles are arranged, the decision-making process showing whether there is an intention to adapt or not to adapt to climate change is not unidirectional. The presence of an arrow connecting various types of behavioral drivers indicates that farmers' behavior does not follow a linear progression among these drivers.

Identifying a singular, linear process in which various behavioral drivers interact to influence farmers' adaptive intentions is not only challenging but also counterproductive. The interdependence and mutual nature of these behavioral drivers make it difficult to isolate their individual impact. Multiple interconnected factors come into play in shaping their decisions. For example, farmers' financial resources (including all types of capital) may influence the experiences or expertise they have, such as having a specific adaptation measure on the farm (Luther et al., 2020). Furthermore, if a farmer has directly witnessed a climate emergency event (experiential type), it can influence their perception concerning climate change (cognitive type). Similarly, how individuals perceive climate change may also determine whether they have already adopted specific adaptive measures rooted in prior experiences (Lujala et al., 2015). Hence, this complex interplay between different drivers and perceptions significantly shapes farmers' decision-making processes regarding adapting to climate change.

3.3. Discussion

The country with the highest contribution of research related to farmers' adaptive behavior to climate change was Iran. This can be attributed to the significant pressures on the country's water resources. Of the fourteen studies reviewed, nine focus specifically on particular events, especially droughts. For instance, temperature increases ranging from 2.5 °C to 5 °C have been observed in Iran between 1960 and 2005 (Azadi et al., 2019a), along with twenty-three consecutive years of reductions in rainfall (Zobeidi et al., 2016). These effects have also become visible in the agricultural regions of the country, such as Kerman province (Asrari et al., 2022).

However, this trend is evident in the rest of the studies as well, with the vast majority of adaptation phenomena being related in some way to water availability, highlighting its role as a key driver of adaptation (Adam et al., 2018; Burchfield and Poterie, 2018; Theron et al., 2022). Similarly, access to water, even when regulated by the government, significantly influences farmers' decision-making processes, including decisions to abandon agriculture (Alston et al., 2018). Furthermore, research indicates that regions with well-developed water management infrastructure are better equipped to adopt innovative agricultural practices, thereby enhancing resilience to climate change (Wu et al., 2023).

Understanding these decision-making processes is critical, and several theories can provide insights into how farmers perceive and respond to these threats. The most common theory employed in the reviewed articles was PMT, which originated in 1975 as an explanation for people's responses to fear appeals (Rogers, 1975). This theory has been used to investigate how farmers perceive climate risks and their willingness to incorporate adaptive behaviors (Grothmann and Patt, 2005; Purwanti et al., 2023; Villamor et al., 2023). The primary focus of PMT is the cognitive processes of threat appraisal and coping appraisal. Threat appraisal involves evaluating the severity of a potential threat and one's vulnerability to that threat; meanwhile, coping appraisal assesses the efficacy of the recommended preventive behavior and the individual's self-efficacy in executing that behavior (Rogers, 1983). These processes assess how individuals perceive threats and determine their intention to modify behavior accordingly based on those perceptions (Maddux and Rogers, 1983). PMT has been widely applied across various fields to understand how people respond to health risks, environmental hazards, and other threats. Comprehending how farmers process climate change risks is crucial because it relates directly to their learning and reasoning processes. Farmers' perceptions of the relative benefits, costs, and risks associated with a given practice influence their intention to adopt it or not (Castro Campos, 2022; Dessart et al., 2019). Furthermore, the impact of farmers' beliefs is not homogeneous across all types of adaptation practices, their responses to climate events vary depending on the nature of their beliefs and how they perceive the potential effects of these events (Zhang et al., 2020).

Our review has identified a wide range of adaptation strategies, demonstrating the diverse approaches farmers take to cope with climate change. The prominence of farming practices such as soil conservation, input management, and the use of adapted crops highlight a strong emphasis on sustainable agricultural techniques to maintain productivity even in challenging conditions (Fantappiè et al., 2020). Agroecological methods appear to be crucial for building resilience, as they play an essential role in enhancing soil health and optimizing resource use (Altieri and Nicholls, 2017). The frequent reference to irrigation improvements highlights the important role of efficient water management in agriculture; especially since improved irrigation practices are pivotal in mitigating water scarcity impacts (Fischer and Sanderson, 2022).

Furthermore, implementing financial measures like obtaining insurance and accessing credits demonstrate the important function of financial mechanisms in mitigating climate-related risks. These strategies offer a safety net that enables farmers to make investments in adaptive measures and recover from climatic shocks (Hirons et al., 2018). Livestock-related adjustments, such as the management and sale of livestock, provide flexibility and additional income streams that are essential for supporting livelihoods during climate variability (Amfo and Ali, 2020; Radolf et al., 2022). Diversifying income with off-farm jobs also highlights a strategic shift to decrease dependency on agriculture, ultimately improving overall household resilience (Kumar et al., 2023; Rahman et al., 2023). Migration and community-based adaptations emphasize the broader social and collective dimensions of resilience, showing the importance of social networks and community actions in climate change adaptation (Chaudhury et al., 2017; Wang et al., 2021).

The results show the interplay of different elements influencing farmers' adaptive behaviors toward climate change, emphasizing the need for a comprehensive approach to addressing these drivers. Cognitive elements, which were the most frequently cited, highlight the importance of psychological processes in farmers' decision-making. This finding is consistent with previous research suggesting that farmers' beliefs and perceptions about climate change significantly influence their willingness to adopt adaptive measures (Feola et al., 2015; Talanow et al., 2021). The significance of cognitive drivers suggests that improving farmers' comprehension and knowledge of climate risks may be a key approach to promoting adaptive behavior (Esham and Garforth, 2013; Yazdanpanah et al., 2024).

In addition to cognitive factors, socio-demographic characteristics - such as age and education level - were identified as significant drivers. This aligns with prior research suggesting that younger and more educated farmers are more likely to adopt innovative practices (Ali and Erenstein, 2017; Doherty et al., 2021). These results suggest that targeted interventions focusing on younger and more educated farmers could be more effective in promoting adaptation. Furthermore, situational drivers such as market conditions and institutional support emphasize the external influences on farmers' adaptive capacities (Kassie et al., 2013; Marie et al., 2020; Thi Lan Huong et al., 2017). Additionally, strong social connections are important and can contribute to more effective adaptive responses (Esham and Garforth, 2013; Wood et al., 2014). Farm-specific characteristics, such as size, highlight the diversity in adaptive capabilities, as larger farms typically have greater resources for implementing adaptive strategies (Jha and Gupta, 2021; Ochieng et al., 2017). These insights emphasize the need for a multifaceted approach that incorporates cognitive, socio-demographic, situational, and financial factors to effectively understand farmers' adaptive behaviors.

4. Case study of Colombia

The 3F-SEC framework illustrates and summarizes the different drivers that influence farmers' decision-making process to adapt to climate change (Fig. 5). These factors have a complex interaction in which there is no single unidirectional effect. The reciprocity and complexity of these interactions result in a network of relationships that translate into diverse impacts on farmers, depending on their specific circumstances. To illustrate this, we include the cases of four different farmers in central Colombia and how they adapt to climate change. These types of farmers were identified during fieldwork in the region from October 2022 to February 2023.

Farmer 1 is an eighty-year-old male living in a village where no weather emergencies have been reported. He perceives himself as less vulnerable to climate change and does not see it as a threat to him or his farm operations. Consequently, he has not taken any steps to adapt his farming practices and reports no intention to do so. This mindset can be attributed to his limited exposure to emergencies attributed to climate change, which affects his perception and reduces his motivation for adaptation. However, younger farmers in the same village who have had similar experiences show a greater tendency to adapt their farming practices, so his advanced age may be another crucial factor in his low willingness to adapt.

Within the decision-making process, different authors have studied how age influences it (Huang et al., 2015; Josef et al., 2016; Rolison et al., 2013; Tymula et al., 2013; S. Wood et al., 2005). Similarly, older adults are more risk-averse than younger people when in uncertainty scenarios (Zamarian et al., 2008). However, people often manifest this risk aversion by simply avoiding making a decision (Blanchard-Fields et al., 2007; Mather, 2006). This can be directly associated with elderly

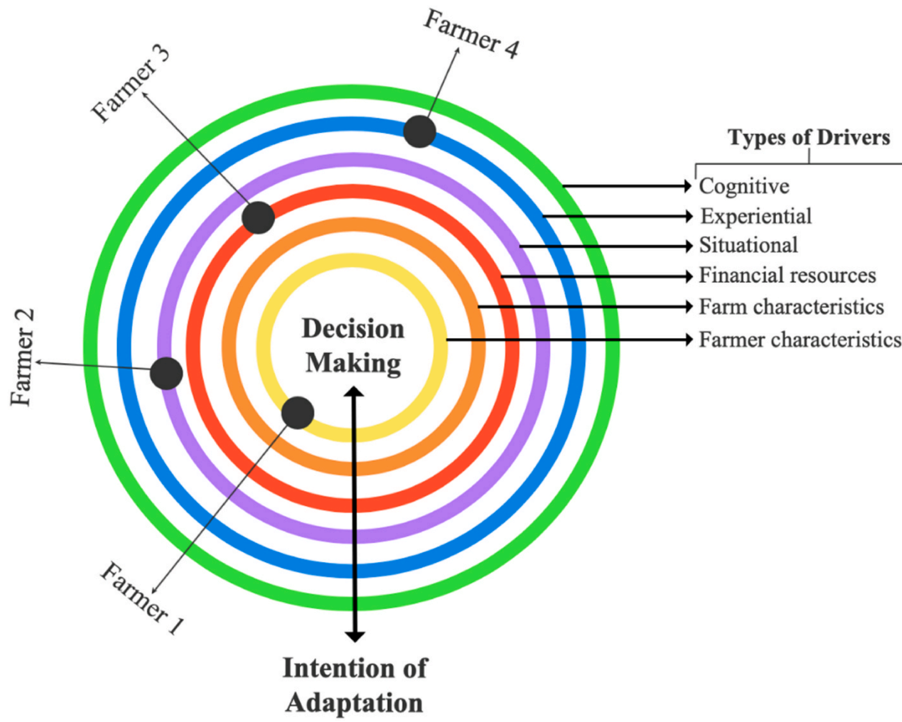

Fig. 5. 3F-SEC Framework for the case of Central Colombia.

farmers avoiding the decision of whether or not to adapt their farming operations to climate change.

The decision-making process of elderly adults differs significantly from that of younger adults (Sproten et al., 2018). Older adults have been found to involve emotions and affective processes within their decision-making, which results in postponing decisions (Zamarian et al., 2008). Research shows that they tend to rely more on their emotional processes than on analytical thinking; similarly, they also tend to remember their past choices more favorably, ignoring any negative aspects they may have encountered while making decisions (Mather and Johnson, 2000). Consequently, this aversion to decision-making among elderly adults may lead them to refrain from taking appropriate measures, such as adapting to climate change.

Other studies have analyzed other variables in addition to age. For instance, it has been found that although age has a negative correlation with the adoption of measures, participation in groups, such as cooperatives, has a positive correlation (M. Li et al., 2021). An example is the case of Farmer 2, a woman in her sixties who experienced two droughts in 2013 and 2016 that were considered emergencies. Thanks to her active participation in a farmers' association in the municipality, she learned to use agroforestry practices to mitigate the impacts of droughts on her farm.

Community relationships are responsible for influencing farmers' decision-making processes. For example, research has shown how these relationships promote social resilience within communities (Tompkins and Adger, 2004). Similarly, the influence of associations, such as cooperatives, on farmer behavior and decision-making has been studied before (Abebaw and Haile, 2013; Hao et al., 2018; Manda et al., 2020; Wossen et al., 2017). Since there is an interrelationship between institutions and people in adaptive processes (Adger, 2003), it is to be expected that associations influence the adaptive measures that farmers choose. Moreover, when people have had experiences that affect the whole community, such as droughts, they are important in forming the collective memory of the community, as it influences the formation of social networks and collaborative efforts to overcome similar situations in the future (Folke et al., 2005).

Farmer associations play a crucial role in influencing the adoption of measures by farmers through the active sharing of information (Abdulai, 2016). Farmers often rely more on their respective associations for advice and support than on extension services (Al Zadjali et al., 2013). This is even more evident when the main role of the associations is to promote innovation and provide more access to technologies and inputs (Chagwiza et al., 2016). For this reason, it is more likely that one of the recommended measures will be adopted when belonging to an association (Abdulai and Huffman, 2014; Ji et al., 2019). These results highlight the importance of agricultural association membership in the decision-making process.

On the other hand, it has been shown that people from lower socioeconomic backgrounds and women tend to have a lower capacity to adapt to climate change (Ranasinghe et al., 2023). Likewise, it has been found that there is a positive correlation between indicators of financial status, such as per capita income, and the adoption of new agricultural practices (Andaregie and Astatkie, 2021; Kisaka-Lwayo, 2008; Singh et al., 2018; Tompkins and Adger, 2004). Farmer 3, who is a seventy-two-year-old woman with a high income, exhibits this behavior. Although she has not had any direct experience with climatic emergencies on her farm, she sees her farming operations as being threatened by climate change and feels that her farm is under threat. Based on her perception, she is determined to adapt her practices to counteract the effects of climate change, such as the use of organic fertilizers and agroforestry practices.

Although income is discussed as a driver of farmer behavior, it is not only limited to farm income; non-farm income has also been found to be positively correlated with adopting new farming practices (Boulay et al., 2012). The same is true for proxy variables for wealth, such as farm size (Luther et al., 2020). Similarly, income and experience have been found to significantly influence preferences for adaptive practices (Ayanlade et al., 2018). Income serves as a bridge between several factors in this context. For example, farmers with higher incomes have better access to credit and tend to participate more in agricultural associations; this in turn translates into greater access to extension services and inputs from these associations, such as improved seeds (Mugumaarhahama et al., 2021).

Financial aspects, thus, play an important role in decision-making.

Farmers are often constrained by their income level, as their financial status limits the possibility of adopting certain measures. This is because, in many cases, adapting requires an initial investment that farmers do not have access to (Pye et al., 2020). As a result, those who do adapt tend to have higher incomes than those who do not (Alidu et al., 2022). Moreover, some authors have even suggested that to incentivize adoption, per capita income should be increased (Borchers et al., 2014). It is evident, then, that financial considerations strongly influence decision-making in farming communities.

Weather emergencies impose additional pressures on farmers, underscoring the necessity for them to adapt to these altered conditions at both individual and community levels (Budhathoki et al., 2020). Numerous research studies have explored how encounters with climate emergencies influence farmers' decision-making processes regarding the adoption of adaptive measures on their farms (Brügger et al., 2021; Marlon et al., 2019; Myers et al., 2013; Ogunbode et al., 2019). Farmer 4 is a man in his forties who lives in a village where several landslides have been experienced because of heavy rains. The geographic proximity of these events has reduced his psychological distance from climate change. This means that he believes that climate change is already occurring in his village and will affect farmers like him. As a consequence, this farmer has a high intention to adapt to climate change. For example, he commented on diversifying his production and a particular interest in planting more trees on his farm and the possible construction of a retaining wall.

When farmers experience climate emergencies, emotional reactions can be triggered that prompt them to take direct action to mitigate potential effects within their farming operations (Demski et al., 2017). Given this, it is necessary to understand these experiences, as they significantly influence farmers' decisions regarding climate change adaptation (Boissière et al., 2013). Furthermore, these individual experiences and their perceived spatial distance to the effects of climate change play an important role in farmers' behavior (Asuero et al., 2012; Lujala et al., 2015). Further understanding how individual factors contribute to farmers' responses is, therefore, essential for effective planning and implementation strategies aimed at enhancing climate change adaptation among agricultural communities.

When individuals encounter a situation, they engage in a process of comparative analysis between their present circumstances and previous experiences. This process facilitates the examination and assessment of the current situation (Marx et al., 2007). When farmers perceive differences between current conditions and their experiences, they attribute these changes to the impact of climate change on their farming operations. In addition, the frequency with which these climate changes occur influences the farmer's decision-making process. First, it helps them determine whether climate change is occurring (Weber, 2010). Second, the more frequent the climate anomalies, the more skillful farmers will be in selecting the most appropriate measure for each event they experience (Enete et al., 2016).

Our research results reveal the complex interplay of drivers influencing farmers' decision-making on climate change adaptation. Farmer 1's reluctance to adapt, despite advanced age, reflects the combination of perceived vulnerability and exposure to climate-related emergencies. In contrast, Farmer 2's active involvement in a local farmers' association highlights how community relationships promote adaptive behaviors; for example, adopting agroforestry practices during droughts. Additionally, financial considerations influence Farmer 3's willingness to adapt due to her high income, underscoring the link between socioeconomic status and adaptation behaviors. Furthermore, Farmer 4's increased desire to adapt after experiencing events like landslides emphasizes how direct experience shapes these behaviors. Recognizing these dynamics can aid policymakers in devising tailored strategies for encouraging climate change adaptation within agricultural communities.

5. Conclusions

Growing concern about the potential effects of climate change on the agricultural sector has led to an increase in research on farmers' behavior and decision-making on adaptation. In light of this, the present study has set forth two key objectives. This study aimed to identify the multitude of factors that significantly influence farmers' decisions regarding the adoption of climate change adaptation strategies, and to shed light on the complex interrelationships of these drivers amid uncertainties related to climate change. Based on a systematic literature review of 87 articles on farmer adaptation to climate change, we propose the 3F-SEC framework to provide a holistic view of all factors influencing farmer behavior. We identify 179 factors categorized into cognitive elements, situational factors, socio-demographic characteristics, and farm-specific attributes as prominent drivers influencing farmers' adaptive behavior.

Cognitive drivers, including beliefs about climate change consequences, are particularly significant, underscoring the role of psychological processes in adaptation. Socio-demographic characteristics such as age and educational level, as well as situational factors like market conditions and institutional support, also play critical roles. The complex interdependence of these factors highlights the need for integrated approaches to understanding and supporting farmers' adaptation intentions. The cases of four farmers in central Colombia illustrate how these factors interact in diverse contexts, reinforcing the necessity of context-specific interventions. This highlights that farmers' decision-making processes are influenced by a complex interplay of these factors, creating diverse impacts depending on individual circumstances.

Although the study is based on 87 articles from the WOS database, future research could expand the scope to include systematic literature reviews from other databases such as Scopus. Additionally, integrating supplementary case studies from different regions would facilitate a more comprehensive comparison and extension of insights from the 3F-SEC framework. This approach would contribute to a deeper understanding of the multifaceted drivers influencing farmers' adaptive behavior in response to climate change.

Policymakers need to prioritize strategies that address the complex nature of farmers' adaptive behavior as outlined in the 3F-SEC framework. If the goal is to strengthen cognitive involvement, then customized educational initiatives and improved access to financial support, such as credit and insurance, could be facilitated. Additionally, enhancing situational factors by developing robust water management infrastructure to address both droughts and flooding, along with facilitating market access will significantly impact farmers' adaptive capacities. By addressing these key areas, policymakers can create an environment that enables farmers to make informed and effective adaptation decisions, potentially enhancing the sustainability of agricultural practices in the face of climate change.

CRediT authorship contribution statement

Alexander Cano: Writing – original draft, Investigation, Formal analysis, Data curation. **Bente Castro Campos:** Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Alexander Cano reports financial support was provided by German Academic Exchange Service. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jrurstud.2024.103343.

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