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REVIEW

Climate change awareness, perceived impacts, and adaptation from farmers' experience and behavior: a triple-loop review

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Abstract
Individuals and communities socially construct risk, and societies with greater risk perception may be more apt to mobilize or adapt to emergent threats like climate change. Increasing climate change awareness is often considered necessary in the first stages of the adaptation process to manage its impacts and reduce overall vulnerability. Since agriculture is affected by climate change in several ways, farmers can provide first-hand observations of climate change impacts and adaptation options. This paper aims to identify the current research trends and set the future research agenda on climate change awareness, perceived impacts, and adaptive capacity from farmers' experiences and behavior. We analyzed a portfolio of 435 articles collected from WoS and Scopus databases between 2010 and 2020 using bibliometrics. From the original portfolio, we select 108 articles for a more comprehensive and systematic review. Publication trends and content analysis have been employed to identify influential work, delineate the mental structure of farmers' beliefs and concerns, and identify main research gaps. The comprehensive analysis reported (1) farmers' socio-demographic characteristics influencing farmers' perceptions; (2) awareness and changing climate evidence due to human activity; (3) the main perceived effects (rising temperatures, changing rainfall patterns, and extreme events); (4) the most relevant adaptation measures (crop changing and soil/water conservation techniques); and (5) factors and barriers limiting adaptation (lack of information, credit, and expertness). The review outlines the main gaps and their drivers to help future researchers, managers, and decision-makers to prioritize their actions according to farmers' concerns and their adaptive capacity to reduce farming vulnerability.

Keywords Climate change · Awareness · Perception · Adaptive capacity · Behavior · Farmers

Introduction

Its scale, complexity, and controversy have made climate change one of the most globally debated risk representation objects (Li et al. 2017). Climate risk is directly linked to vulnerability because climate change impacts might result from the interaction of climate-related hazards with vulnerabilities of societies and systems exposed (Selvaraju 2012). Individuals and communities socially construct risk perception, and societies with greater risk perception may be more apt to mobilize or adapt to newly emerging threats (Smith and Mayer 2018; Soubry et al. 2020). One of the unique characteristics of climate change is that it is often seen as a distant psychological threat (Sterman and Sweeney 2007), whose effects and risks are spatially and temporally differentiated (Woods et al. 2017). In other words, its effects are assumed to impact individuals and communities that are geographically, temporally, and even generationally removed from themselves (Azadi et al. 2019a). Yet, events perceived to be "closer" to an individual tend to be more salient and have a more decisive proximate influence on individual decisions (Spence et al. 2012), thus increasing the perceived risk of climate-related extreme events (Azadi et al. 2019b; Bo and Wolff 2020).

Climate change is both a physical and social phenomenon (Hulme 2009), and individuals are not "blank slates" receiving information about climate change (Wolf and Moser 2011).

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Personal experience and local knowledge, together with social learning exchange, may help to reduce agricultural systems' vulnerability. Along with different approaches, de Boer et al. (2016), Eitzinger et al. (2018), and more recently, Tiet et al. (2022) point out that individuals manage to trade off the information they receive about the consequences of climate change with their previous beliefs and local know-how about changes in weather patterns and past climate-related events in their area, thus generating adaptive behaviors able to integrate both types of knowledge. Furthermore, a recent study by Rust et al. (2022) confirmed how delving into farmers' experiences could increase trust in others' recommendations, indicating that social learning through similar peers — such as other farmers or water managers — is important for farmers to be persuaded to act.

Many have argued that deepening personal experience could be the first step for reducing individual and community psychological distance from climate change while promoting behavioral change (Phadke et al. 2015; Asplund 2016; Geiger et al. 2017; Wi 2019). Accordingly, social and behavioral sciences have discussed associative processing methods and the nature, extent, significance, and influence of the personal experience of climate change over the past decade to understand how it affects adaptive capacity, that is, the ability to moderate impacts or to cope with the consequences of climate change (Myers et al. 2013; Reser et al. 2014; van der Linden 2014; Broomell et al. 2015; Marlon et al. 2018). Among others, Reser and Bradley (2020) highlighted four main themes conditioning psychological distance: (1) the extent and underpinnings of public acceptance or "belief" regarding anthropogenic climate change; (2) the effectiveness of communication regarding climate change and the level of public engagement; (3) the nature of environmental risk awareness, perception, and response in the context of climate change; and (4) the unfolding and increasingly dramatic local and global biophysical environmental changes, events, and conditions attributed to climate change.

Increasing awareness is often considered necessary in the first stages of the adaptation process to manage climate change impacts and reduce overall vulnerability, because the degree of awareness tends to reflect the level of exposure to climate risks of a community (Ado et al. 2019). Consequently, being aware requires recognizing that climate change is a problem and understanding the risks and impacts that need to be dealt with (Lieske et al. 2014). On the other hand, risk perception is how individuals receive information or stimuli from their environment, transform it into psychological awareness, and (re)act accordingly. In other words, it refers to a mental construct, an individual's assessment of the probability of a particular event and its consequences, or a subjective estimation of the nature of a threat and its severity (Azadi et al. 2019a). Although counterintuitive, some authors concluded that higher awareness of climate change might relate to lower risk perception due to risk normalization (Luis et al. 2018). Consequently, individuals could develop psychological risk minimization strategies to curtail perceived threats and psychologically adapt to the situations. Therefore, timely and accurate risk perception is an essential determinant of intentions and for the choice of adaptation methods (Deressa et al. 2011). In the case of farmers, poor risk perception may lead to maladaptation (i.e., fatalism, denial, and wishful thinking) and increase their vulnerability to climate change, while accurate risk perception may positively influence the farm level's adaptation process (Le Dang et al. 2014).

Recency effects and occurrence of extreme meteorological events, such as an exceptionally rainy winter or a very dry summer, or sudden changes in daily temperature, can determine both risk awareness and perception (Ng'ombe et al. 2020). An individual's level of concern about climate change can also vary by problem scale; problems often seem more urgent when perceived as local (Maas et al. 2020). For example, Schlüter et al. (2017) highlighted that in various behavioral models, individuals' awareness and perception are input factors for climate change adaptation, while the behavior is the output. Otherwise, "belief" in climate change risks was heightened by the awareness of more observable climate change-related phenomena (e.g., extreme weather events or droughts) but it was not a direct cause of adaptation behavior (Li et al. 2021). Likewise, socio-economic and demographic variables such as gender, age, education, and income affect climate change awareness and its risks (Azocar et al. 2021; Mallappa and Shivamurthy 2021). Likewise, group norms and ideology, aligned with political party affiliation, have been shown to influence an individual's belief in climate change (Dietz 2020).

Farmers develop their activity dealing with the complexity of interrelated nature and human systems characterized by biophysical conditions and socioeconomic transformations (Abid et al. 2016a, b). Consequently, farmers are in a favorable position to offer first-hand observations, while providing a deeper understanding of climate change manifestation, relevance, effects, and narratives (de Matos et al. 2020; Talanow et al. 2021). However, as some authors suggested, "seeing is not believing" for farmers, and even after being impacted by climatic extremes, many continue to be resistant to face climate change (Houser et al. 2019). Anyway, the nature and severity of some perceived impacts of climate change (e.g., increasing temperatures, heat stress, droughts, rainfall decrease, and changes in seasonality, pests, and diseases) reinforce the identification of climate change "hotspots," in which agricultural activity could be heavily affected (Shukla et al. 2016). According to de Sherbinin (2014), the "hottest hotspots" are those in northern latitudes (concerning the Equator), which are predicted to experience significant temperature changes.

The two most prominent hotspots are the Mediterranean, which will see declines in mean precipitation and has been confirmed as a "climate change hotspot for highly interconnected climate risks" (IPCC 2022), and North-Eastern Europe, which will suffer increases in winter precipitation and strong regional warming relative to the global mean. Likewise, Central America, southern Africa, and South Asia are predicted to increase precipitation variability. Agricultural vulnerability will increase in these regions where water availability is currently problematic (Pausas and Millan 2019; Tuel and Eltahir 2020). For example, in the Mediterranean region or the Southern European coast, the relative profitability of agriculture can be significantly reduced, and the loss of agricultural land and farmland value can vary from 60 to 80% by 2100 (EEA 2019).

Accurate bottom-up knowledge on the level of farmers' climate change awareness and perception enables policy-makers and managers to understand and re-think climate change policies at the local level, which is essential to address agricultural risks in climate change hotspots (Simane et al. 2016; Asare-Nuamah and Botchway 2019). Farmers' attitudes considering both perceived impacts and adaptation strategies have been only relatively explored through case study analyses (Etana et al. 2020; Tesfahun and Chawla 2020; Ahmed et al. 2021; Nalau and Verrall 2021). With this paper, we aim to comprehensively review the last decade's literature on farmers' behavior particularly focusing on which driving factors are building the scientific debate on farmers' personal experience and local knowledge. We focus on two main research questions:

RQ1: What is the current publication trend at the global scale on climate change awareness, perceived risk, and adaptive capacity from farmers' experiences (e.g., authors' profile, sources, affiliated countries and institutions, methods, keywords, and themes)? (Bibliometric analysis, BA)
RQ2: How do farmers' attitudes and perspectives determine their perception regarding climate change awareness, impacts, and adaptation measures and barriers? (Systematic literature review, SLR)

The remainder of this paper is structured as follows. The "Material and methods" section focuses on methodological aspects, where the use of BA and SLR is explained, and the process of their implementation is described. The results of the BA are provided in the "Bibliometrics" section, focusing on core subject areas, journals and authors' profiles and co-citations, the temporal evolution of the research and co-occurrences, and ways in which risk, awareness, and perception are being clustered to address farmers' behavior on climate change. The "Literature review of farmers' behavior" section synthesizes findings from the SLR by presenting a detailed analysis of six main topics: (a) socio-demographic farmers' profile, (b) awareness, (c) perceived impacts, (d) adaptation measures, (e) factors affecting adaptation, and (e) adaptation barriers and constraints. Opportunities and limitations to advance current research on perceived risks and adaptive capacity are finally discussed in the "Discussion and further research" section, including final remarks and implications for future research.

Material and methods

We combined BA and SLR to provide deeper state-of-the-art knowledge of farmers' attitudes regarding climate change, considering awareness, perceived risks, and actions to increase adaptation. BA contributes a descriptive and statistical evaluation of scientific publications output for tracking progress and tracing knowledge of a research field (Opejin et al. 2020; Mao et al. 2021). The SLR is more robust than the traditional narrative review owing to its thorough, replicable, and transparent procedures, able to identify, assess, and interpret the available records on a particular theme with a broader motive to understand recent progress, find out the scientific gaps, and delineate the future directions (Crane et al. 2017; Mengist et al. 2020; Shaffril et al. 2021). Both tools can simplify the dynamic and complex linkages between different documents and associated information and entail visualization of the knowledge structure using data reduction techniques (Moral-Munoz et al. 2019).

Data collection

Web of Science and Scopus databases served for this study. The first one is the most authoritative citation database and has been widely applied for bibliometric analysis, while Scopus provides coverage of social sciences and farmers' behavior-related publications (Das and Goswami 2021). The search was conducted in May 2021 and data from the period 2010–2020 were analyzed. The last decade was confirmed as the hottest decade since record-keeping began 140 years ago, according to the world's temperature data and historical observations collected by the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA).

The review process followed a screening and inclusion criteria protocol in which results were filtered by language (English), type of publication (article or review), and core collection (no subject area restriction). The setting of the conceptual boundaries was based on the terms "climate change" + "risk," "impact," "perception," "adaptation," and their derivations, combined with terms describing their application in a rural environment (e.g., "farmer," "irrigation"). We used a combination of a triple query protocol (Table 1).

Table 1 Triple query protocol combined to carry out the BA analysis

Protocol 1	TITLE-ABS-KEY (climat* chang* OR global chang* OR warm*)	*AND*	TITLE (impact* OR risk*)	*AND*	TITLE-ABS (farm* OR irrigat* OR agricult*)
Protocol 2		*AND*	TITLE (aware* OR perception* OR perceiv* OR attitud* OR behavior* OR experience OR belief*)	*AND*	TITLE-ABS-KEY (farm* OR irrigat* OR agricult*)
Protocol 3		*AND*	TITLE (adapt*)	*AND*	TITLE-ABS (farm* OR irrigat* OR agricult*)

The combination of each query returned 5784 and 1579 results in the Scopus and WoS databases, respectively. We applied a manual filtering process based on delete duplication (after normalizing the document's titles and first author's last name to ensure consistency between databases) and title screening. Consequently, 1438 results were ignored, and 4104 results were excluded after title screening for different reasons: the method was partially or totally out of the social scope of the study (e.g., life cycle assessment, modeling, cost–benefit analysis, ecosystem-based approach, indicators meaning); the topic was not significantly related to the field (e.g., projections on climate change impacts, perception from agriculture students and advisors, prospective scenarios and regional policy design, and climate change variability vs meteorological records); and the context expanded beyond agricultural areas (agroforestry, aquaculture). We consider the remaining 1821 results for abstract screening (512), of which 435 were used for the BA after a second screening process (Online Resource 1). Finally, 108 papers from full-text screening were used for the SLR, selecting those using a survey to collect farmers' attitudes, as this tool can synthesize farmers' perceptions and compare their behavior through a specific questions' typology (Wheeler et al. 2021). Figure 1 presents the snapshot of the data collection and analysis method adopted in this study.

Data analysis

The selected literature was analyzed by considering both quantitative (univariate statistics) and qualitative (thematic analysis) methods. For the BA, data has been analyzed by combining two main procedures: performance analysis and science mapping. According to Rosato et al. (2021), performance analysis provides data about the volume and impact of research using a wide range of indicators and techniques (e.g., word frequency, citation, and counting publications by a unit of analysis). Science mapping, meanwhile, provides first- and second-generation relational indicators to create a spatial representation of how different elements relate to one another (e.g., co-citation, bibliographic coupling, and co-occurrence of keywords). We extracted different elements for each publication, including keywords, author information, institutional affiliation, journals, and citations, which allowed us to determine the academic performance and key issues in the field of farmers' behavior on climate change.

We used the bibliometrix R-package (including the biblioshiny app) and OriginPro 2022 statistical software in combination with the VOSviewer software (version 1.6.17) (Aria and Cuccurullo 2017). The last one is a Java programming language used to create, visualize, and explore maps based on network data and taking a distance-based approach to visualizing a network of clusters in which nodes represent

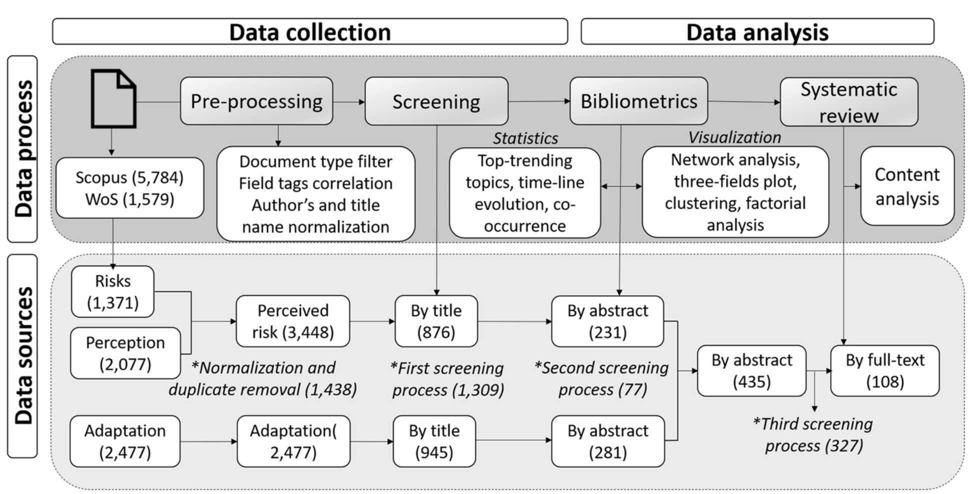

Fig. 1 PRISMA flow diagram of the data retrieval and analysis process

different elements duly organized according to their orders of magnitude (from higher to lower values) (Van Eck and Waltman 2020). For the SLR, a thematic analysis has been conducted with the aim of complementing BA results and minimizing bias. After carefully reading and categorizing the selected corpus of references, core themes and top-level concepts discussed in the literature have been analyzed by case study contributions (Pizzi et al. 2020). Finally, a causal-loop diagram (CLD) provides a straightforward graphical representation of the most relevant issues and interactions across the triple-loop dimensions (awareness, perceived impacts, and adaptation measures and barriers) obtained from the thematic analysis. This heuristic tool supports meaningful hypotheses for data gathering and theory building (Coletta et al. 2021), and can be used as a diagnostic mechanism that helps to identify potential gaps in current farmers' experiences and behaviors.

Bibliometrics

This section presents the BA results in detail. First, we analyze the trends of publications considering the most influential authors and references ("Authors" section). Then, we present the results of sources co-citation analysis and category co-occurrence analysis to explore the discipline distribution and the most influential documents ("Sources and documents" section). The results of keyword plus analysis and burst detection are demonstrated in the "Keywords" section, while the "Themes" section reveals the main themes on which farmers' behavior on climate change is focused on.

Authors

Our collection comprises 435 documents (422 research articles and 13 review articles) that account for 1428 authors from 65 countries, with a co-author's ratio per document of 3.8 and a collaboration index of 3.44, with a high level of co-authorship (only 28 single-authored documents). Figure 2 synthesizes the authors' plot results. The analysis reveals that the annual production of articles on climate change perception and adaptation from farmers' behavior has not been constant over the period considered: recent years have seen rapid growth of this field, with 370 of the total articles published between 2015 and 2020 (i.e., 62 per year, on average, compared to 12 per year between 2010 and 2014).

The frequency of publication by authors is calculated through Lotka's Law, concluding that 1256 authors (88%) have written just one document. The authors with the highest number of papers are Sha Fahad and Jianling Wang (Jiaotong University, China) (Huong et al. 2017; Fahad and Wang 2018; Fahad et al. 2018, 2020), Jinxia Wang (Peking University) (Wang et al. 2010, 2019; Hou et al. 2015; Zhang et al. 2017), Muhammad Abid (University of Islamabad, Pakistan) (Abid et al. 2015, 2016a, 2016b, 2019; Khan et al. 2020a, b), Samuel A. Donkoh (University for Development Studies, Ghana) (Kusakari et al. 2014; Azumah et al. 2017; Adzawla et al. 2019b, 2020; Tetteh et al. 2020), and Uttam

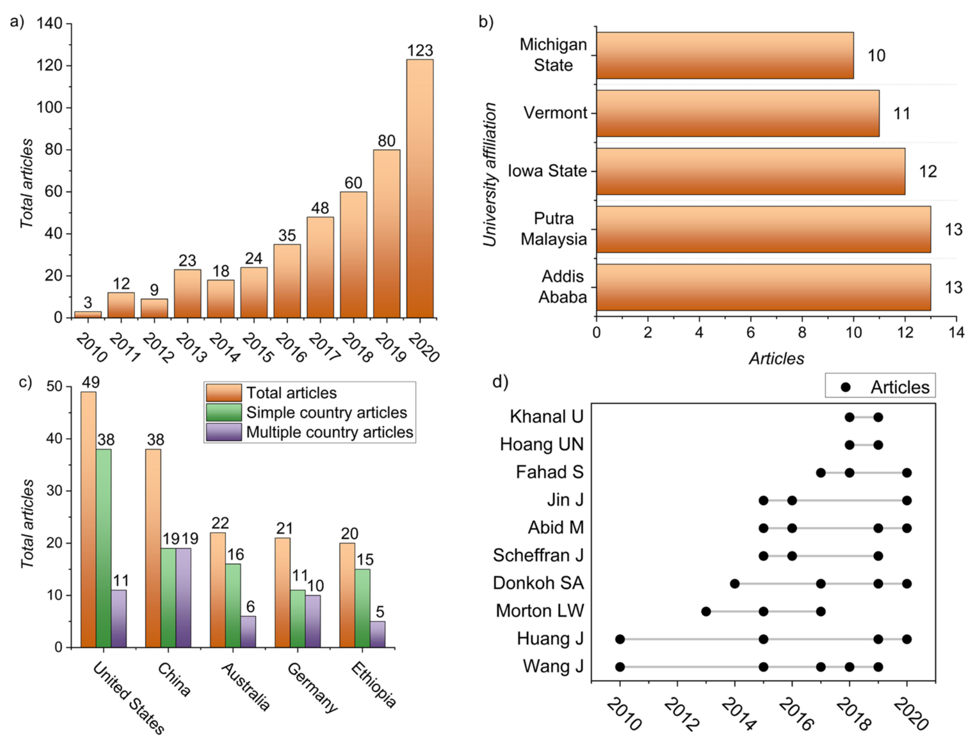

Fig. 2 Authors' output by annual production (**a**), top 5 most relevant affiliation (**b**), top 5 corresponding authors' country (**c**), and top 10 authors' production over time (**d**). Note: "Wang" in d includes works from Jianling Wang and Jinxia Wang

Khanal and colleagues (Queensland University, Australia) (Khanal et al. 2018a, 2018b, 2019a, 2019b).

The main topics include climate change impacts on food production, crop vulnerability, crop choice, and determinants of adaptation to extreme weather events, especially from case studies in Pakistan, Nepal, and China. The majority of the top 10 most relevant authors concentrated their activity in the last 3 years, and just four published during the first half of the decade. Likewise, of 669 institutions, the five most relevant authors' affiliations are from the universities of Addis Ababa, Putra Malaysia, Iowa State, Vermont, and Michigan State, while the USA and China lead corresponding authors' countries.

The co-authorship and co-occurrence of leading authors considering fractional counting have been calculated according to three units of analysis: authors, affiliations, and countries. The authors' analysis highlighted 38 co-authorships, duly organized in 14 clusters, with at least three articles published in common. Of them, the strongest collaboration is the cluster led by J. Gordon Arbuckle Jr. and colleagues and focused on farmers' beliefs and perceived risks in the USA, including concepts such as techno-optimism or science-truth to deal with climate change-related issues (Arbuckle et al. 2013a, 2013b, 2015; Roesch-McNally et al. 2017; Gardezi and Arbuckle 2019, 2020). Regarding the affiliation analysis, only three co-authored papers were published by three authors from the same affiliation, while 47 papers from 29 clusters were published by two authors from the same institution. Thus, the field is characterized by a high degree of heterogeneity regarding co-authorship affiliation corpus, which in turn is related to the inclusion of authors' affiliations not primarily focused on climate change studies, such as the top 3 affiliations by co-authored contributions: College of Resources, Science and Technology (*Beijing Normal University*), the Department of Sociology (*Iowa State University*), and the Institute of Agricultural and Resource Economics (*University of Agriculture*, *Faisalabad*, *Pakistan*). The difference in affiliations is also exemplified when considering co-authors' countries: authors' affiliations in co-authored publications sum a total of 90 countries, being 36 countries suitably organized in six clusters, where the one lead by the USA is the most relevant in terms of geographical interdependence in the last 5 years, while a secondary cluster co-led by China and Australia concentrate most authors' citations received in 2018.

Sources and documents

The 435 documents have been published in 174 different sources. Of them, the top 10 journals were considered core sources according to Bradford's Law, which describes how the articles on a particular subject are scattered throughout the mass of periodicals. These journals cover various topics, such as sustainable development, natural resources management, or geographical issues, but only four can be considered climate change journals. Furthermore, eight of the top 10 sources published more than ten articles, making up almost one-third of the library (32.6% of documents) (Table 2). Likewise, source dynamics highlighted 2015–2016 as the period in which core sources growth was faster, considering cumulate occurrences between sources (e.g., *Sustainability* was the journal that had grown more exponentially since 2015, when it added its first occurrence, while *GeoJournal* added their first occurrence in 2018 to increase its significance for nine times in 2020). Moreover, three journals (*Climate and Development*, *Climatic Change*, and *Land Use Policy*) indexed as top quartile journals (Q1) in different WoS categories (development studies, meteorology and atmospheric sciences, and environmental studies) accumulated between one-third and half of their occurrences in 2020 only (Fig. 3).

Besides the number of published documents, we considered additional indicators, related to citations, to eventually identify further sources that appear to be relevant for the scientific community. We distinguished between local and global citations: local citations refer to citations that a reference received from articles included in the collection;

Table 2 Top 10 most relevant journals (including main topic and number of articles)

Journal	Topic	Articles
Climate and Development	Climate change	27
Climatic Change	Climate change	21
Land Use Policy	Urban and rural land use	14
Sustainability (Switzerland)	Sustainable development	14
Environmental Management	Use and conservation of natural resources	13
International Journal of Climate Change Strategies and Management	Climate change	12
Regional Environmental Change	Human and natural systems interactions	12
Environment, Development and Sustainability	Sustainable development	11
GeoJournal	Geographical and spatial issues	9
Mitigation and adaptation strategies for global change	Climate change	9

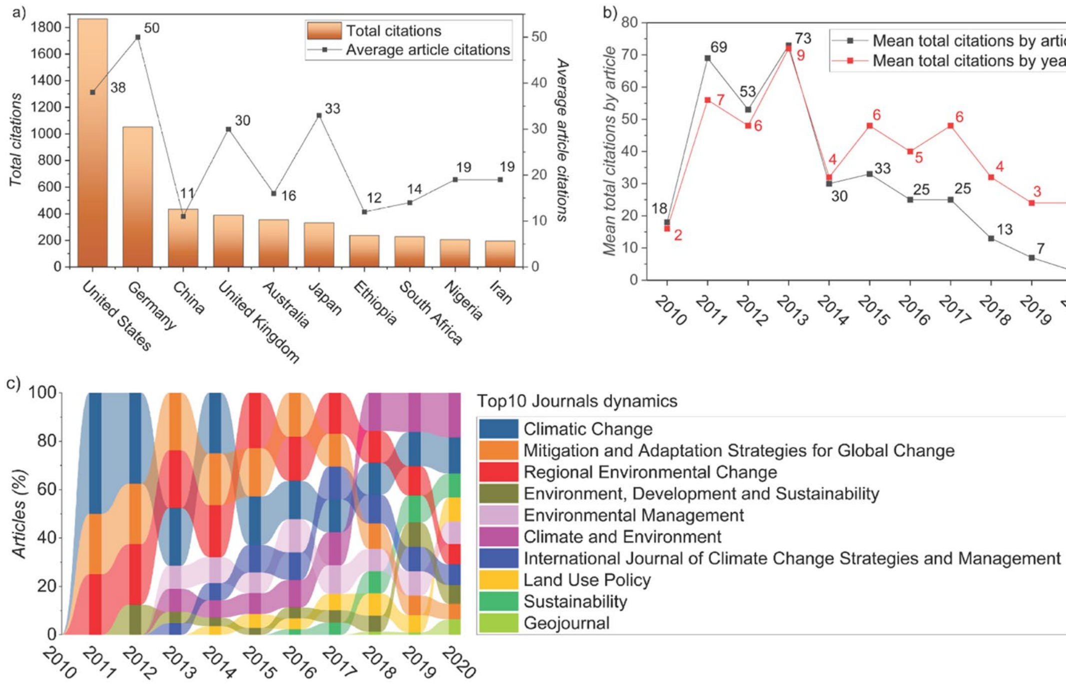

Fig. 3 Most cited countries (**a**), average citation (article/year) (**b**), and main source dynamics (**c**)

in contrast, global citations refer to the total citations that an article from the collection has received from articles not included in the collection, that is, all over the world. Our results (see Table 3) highlight that four out of the ten most cited documents were published on journals (*The Journal of Agricultural Science*, *Journal of Environmental Management*, *Earth System Dynamics*, and *Global Environmental Change*) not included in the top 10 sources (Fig. 3), with *Global Environmental Change* ranking first in terms of total global citations, with more than half of them (473 of 875 citations, 54.1%). The average of total citations per article was 18.6, but higher levels were identified between 2011 and 2013, when 44 articles were published. Regarding local citations, five countries (USA, Germany, China, UK, and Australia) lead the ranking by accumulating more than half (54.8%) of the total local citations.

The local and global citations ratio is 8.62, considering that the 435 documents accumulated 1051 local citations and 8109 global citations. Most documents (239 documents, 54.9%) were not cited at the local level but at the global level (just 45 documents, 10.3%, were not cited globally). Furthermore, the top 10 most cited documents were published between 2011 and 2015 in multifocal journals where environmental and climate change topics are dominant (Table 3). The first two

Table 3 Top 10 most cited documents considering local and global citations

Article (year)	Journal	Local citations	Global citations	Local/ Global ratio (%)
Deressa et al. (2011)	*The Journal of Agricultural Sciences*	66	313	21.1
Bryan et al. (2013)	*Journal of Environmental Management*	56	288	19.4
Fosu-Mensah et al. (2012)	*Environmental, Development and Sustainability*	30	157	19.1
Abid et al. (2015)	*Earth System Dynamics*	28	163	17.2
Hisali et al. (2011)	*Global Environmental Change*	27	132	20.4
Esham and Garforth (2013)	*Mitigation and Adaptation Strategies for Global Change*	21	93	22.6
Arbuckle et al. (2013a)	*Climatic Change*	18	125	14.4
Arbuckle et al. (2013b)	*Climatic Change*	20	130	15.4
Simelton et al. (2013)	*Climate and Development*	18	92	19.6
Manandhar et al. (2011)	*Regional Environmental Change*	18	135	13.3

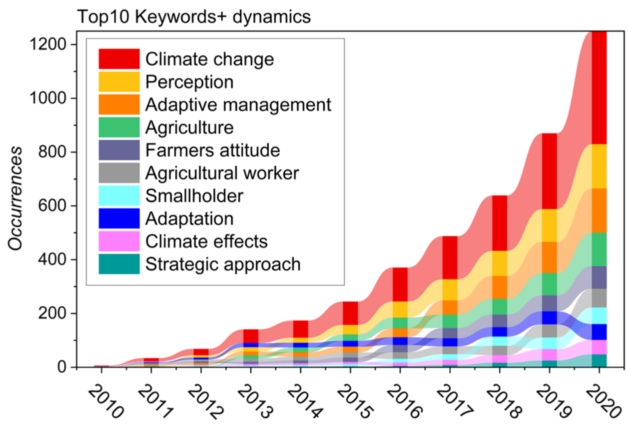

Fig. 4 Keywords + cumulative occurrence evolution for the whole period (2010–2020)

ranked articles are those with the higher number of local and global citations, while the contributions by Esham and Garforth (2013) and Manandhar et al. (2011) score the maximum and minimum values of the ratio, respectively. Otherwise, the local citation ranking can be considered when analyzing the internal consistency of the library regarding mutual recognition between the most-cited contributions.

Keywords

After clustering synonymous keywords across the selected literature, the list of "keywords + " function, which encompasses not only the keywords of the selected articles but also the keywords of the documents that these articles cite, was automatically generated by a computer algorithm. The analysis identified 981 most used author's keywords and 1471 keywords + . Thus, a total of 5327 occurrences have been established, 22.5% (1207 occurrences) of them between the top 10 most used keywords + , identifying a triple focus on the challenging climate scenarios (*climate change*, *climate effects*), the farmers' roles and perspectives (*agricultural worker*, *smallholder*, *agriculture*, *farmers' attitude, perception*), and their capacity to respond to climate change impacts (*adaptive management*, *adaptation*, and *strategic approach*) (Fig. 4). Similar results were obtained at the title and abstract level, although some new keywords appeared, such as *farmers' knowledge* or *food security*. Furthermore, evolution over time reveals that researchers initially tried to relate farmers' behavior on climate change to keywords like *mitigation* and *local adaptation*, while, subsequently, they moved on to *awareness*, *impacts*, and *resilience*, mainly focused on *adapted behavior*, *environmental impact assessment*, and *policy-making* strategies to address *risk perception*, and *vulnerability*. Likewise, although not ranked first, the time scale highlighted the relevance of some methodological tools applied in the research, such as questionnaire survey (Morton et al. 2017; Brussow et al. 2019), interviews (Montgomery et al. 2017; Iniguez-Gallardo et al. 2020), climatological analysis (Tunde and Ajadi 2018; Nkuba et al. 2020), risk assessment (Mubaya et al. 2012; Abdul-Razak and Kruse 2017), cost–benefit analysis (Mitter et al. 2019; Singh 2020), and socio-economic indicators (Tesfahunegn et al. 2016; Quiroga et al. 2020).

Themes

We applied a clustering algorithm on the keyword plus co-occurrence network analysis to delineate the conceptual structure of the farmers' behavior on climate change and define what science talks about and which are the main trends. Callon's centrality index measures a network's interaction or external cohesion degree, while Callon's density index measures the internal strength or cohesion of the network. According to both indexes, research themes can be mapped as "motor-themes" if topics are well developed and are essential for structuring a research field; "basic themes" for those transversal topics with high expectancy in short-term development; "niche themes" for those issues of marginal importance with a lack of external feedbacks; and "emerging or declining themes" for those themes both weakly developed and peripheral for the advance of the research topic. Figure 5 shows the time span of combined

Fig. 5 Research themes evolution considering Callon's centrality and density by time intervals 2010–2015 (**a**) and 2016–2020 (**b**). Methodological notes: Min. cluster freq. 5% based on 1000 keywords + and calculated by the Weight Index (Inclusion Index weighted by word occurrences) with one cutting point (2015)

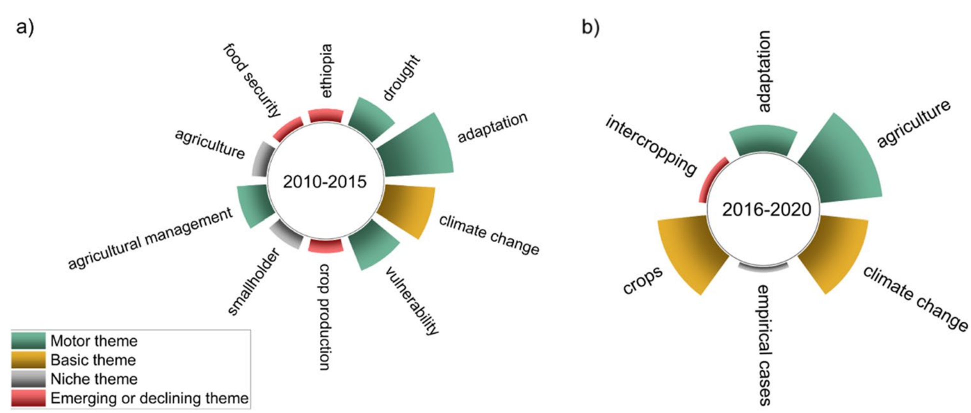

Table 4 Topic clusters identified in 2010–2015 time slice according to main theme, sub-theme(s), and geographical location(s)

Main theme (occurrences)	Main sub-themes	Case study location(s)
Climate change (62)	Perception, adaptive management, farmers' attitude, farmers' knowledge, weather forecasting, vulnerability, sustainability	Australia, Nigeria, Bolivia, USA
Adaptation (18)	Awareness, farmers' perception, irrigation, indigenous knowledge, temperature, precipitation	China
Agriculture (17)	Mitigation, farmer' perception, global warming	USA, arid regions
Vulnerability (11)	Maize, crop rotation, climate change adaptation, water management, potential impacts, agricultural modeling	Sub-Saharan Africa
Agricultural management (9)	Irrigation, climate models, adaptation strategies, water supply, climate change impact	California
Drought (8)	Risk perception, farmers, income	Vietnam
Smallholder (8)	Yield response, rural development, environmental conditions	Mexico, North America
Ethiopia (6)	Water quality, sensory perception, productivity	Ethiopia
Food security (5)	Socioeconomic conditions, social status	Zambia, Zimbabwe, Malawi, South Africa
Crop production (4)	Irrigation system, agrometeorology, water availability	

Callon's centrality and density indexes in two-time slices, 2010–2015 and 2016–2020. According to the obtained results, the number of clusters reduced over time: from ten clusters before 2015 to six since 2016, partially due to a concentration process in which some motor themes have been merged and evolved. Interestingly, the "adaptation" cluster remains the main motor theme for the whole period. In contrast, the "climate change" cluster ranks first during the whole period considering Callon's density index, although tripling the number of occurrences since 2016, reinforcing his dominance as a basic theme. Regarding centrality, some restructuring has occurred among motor and basic themes. For example, "food security" and "crop production" were ranked as core issues (emerging themes) before 2015 but have been progressively included as examples of "intercropping" issues or as part of the basic theme "crops" (like "vulnerability" and "drought" issues). Likewise, "agriculture" was considered a niche theme and "agricultural management" a motor theme before 2015, but they have been progressively included in the "agriculture" cluster. "Empirical analysis" (based on case studies research) appeared as the only niche theme since 2016, highlighting a highly developed but partially isolated research interest.

Conversely, some top 10 most used keywords + (e.g., "perception," "farmers' attitude") are missed as core themes but highly included as clusters' sub-themes. Tables 4 and 5 synthesize the main characteristics of thematic analysis for each period (2010–2015 and 2016–2020). Three main conclusions can be highlighted: (1) clusters on "climate change," "adaptation," and "agriculture" remain in the three main clusters considering keywords + occurrence across both periods; (2) "perception" is considered one of the principal sub-themes in half of the 2010–2015 themes and one-third of the 2016–2020 themes; and (3) "climate change" is the most geographically distributed theme in both periods,

Table 5 Topic clusters identified in 2016–2020 time slice according to main theme, sub-theme(s), and geographical location(s)

Main theme (occurrences)	Main sub-themes	Case study location(s)
Climate change (208)	Adaptive management, perception, farmers' attitude, crop production, decision-making, vulnerability, drought, maize, sustainability, agroecology, farmers' behavior, mitigation	China, Ethiopia, India, USA, Nepal, Ghana, Vietnam, Iran, Uganda, Zambia, Kenya, Malaysia, South Africa, Tanzania, Philippines, Australia, Zimbabwe
Agriculture (59)	Farmers, male, female, risk assessment, environmental policy, education, attitude, livestock, income, government, awareness, crop rotation, drought	Pakistan, Bangladesh, Burkina Faso, USA, Mexico
Adaptation (29)	Temperature, crop, irrigation, planting time, water stress, climate variability	Asia
Crops (27)	Adaptation strategies, climate models, water management, water conservation, extreme weather events, risks, farmers' perception	Developing countries, Nigeria, Brazil, Colombia, Cyprus, Niger
Empirical analysis (7)	Economics, climate-related risks	
Intercropping (2)	Crop, agriculture, adaptation	China

although spatial coverage increased during 2016–2020, especially in Asia, Africa, and the Americas.

Literature review of farmers' behavior

Socio-demographic characteristics

Most studies include a farmers' profile with basic information regarding age, gender, education, farming experience, farm size, and association membership (Online Resource 2). Although age is put out of the analysis in some studies due to its multi-collinearity effect with farming experience (e.g., Abrha and Simhadri 2015), about 70% of the studies include this issue to deepen farmers' socio-demographic profile. The dominant age range is differing: the mean age in studies carried out in Niger (e.g., Ado et al. 2019, 2020) or Vietnam (e.g., Nong et al. 2020) is under 40 years old, while in the Philippines (e.g., Lasco et al. 2016) or Zimbabwe (e.g., Mutandwa et al. 2019) is under 50 years, and the oldest farmers are surveyed in the USA (e.g., Liu et al. 2014) and China (e.g., Zhang et al. 2020). Likewise, some studies apply an "age barrier" on farmers (e.g., 50 years old) as a parameter to delve into the driving factors determining climate change perception (e.g., Idrissou et al. 2020).

Gender and farm size are considered in about half of the studies. Regarding gender, studies are men-focused, being only five studies in which the female gender exceeds 50% (e.g., Liu et al. 2014; Li et al. 2017; Ferdushi et al. 2019; Assan et al. 2020; Chhogyel et al. 2020), and just one specifically addressed to behavior analysis of female farmers (Lawson et al. 2020). Extremes in most common farm size are noted: from less than half a hectare in India (e.g., Esham and Garforth 2013; Aryal et al. 2020; Funk et al. 2020; Islam et al. 2020; Singh 2020; Sujakhu et al. 2020) to 5–10 ha in African countries (e.g., Ochieng et al. 2017; Akinbile et al. 2018; Idrissou et al. 2020), but about 25 ha in Cambodia (e.g., Thangrak et al. 2020) or 70 ha in Hungary (e.g., Li et al. 2017).

Education is included in more than two-thirds of the studies, providing two types of information: years of formal education or degrees achieved. Illiterate and primary education are the dominant categories in half of the studies, mainly located in African countries, such as Benin (e.g., Idrissou et al. 2020), Ghana (e.g., Assan et al. 2020), and Burkina Faso (e.g., Alvar-Beltran et al. 2020), but also in Asian countries, such as Pakistan (e.g., Bacha et al. 2018) or China (e.g., Quan et al. 2019). Otherwise, high school is the highest educational range in 11 studies, although in only three of them the representativeness is higher than 50%: China (e.g., Jin et al. 2015, 2016), the USA (e.g., Arbuckle et al. 2013b), and Hungary (e.g., Li et al. 2017). The farming experience is considered in about 40% of the studies. Surveyed farmers have more than 10 years of farming experience, with only two exceptions: the study by Chepkoech et al. (2020) in Kenya and Elum et al. (2017) in South Africa.

Awareness

Farmer views regarding the leading causes of climate change (e.g., human versus non-human induced) are more divergent than climate change occurrence. Only one in five papers asks about climate change awareness, and from that, 70% reported how farmers agree with statements like "the climate is changing" or "the climate change is occurring" (e.g., Niles et al. 2013; Ndamani and Watanabe 2017; Asrat and Simane 2018; Ferdushi et al. 2019; Biswas et al. 2020). However, only half of the sample delves into statements explaining the causes of climatic change (Online Resource 3). As a common trend, farmers tend to consider that climate is mainly changing because of human activity (e.g., Fadina and Barjolle 2018; Agesa et al. 2019; Roesch-McNally et al. 2017, 2020). For example, in a recent study among farmers in Pakistan, Fahad et al. (2020) revealed that the majority of farmers (73%) have noticed and are aware of the human role in climatic variations, while similar research conducted in South Africa by Elum et al. (2017) increases this evidence until 95% of the farmers. Moreover, few studies reflect how farmers consider climate change a result of human activity and natural changes (e.g., Mase et al. 2015; Abera and Tesema 2019; Amir et al. 2020a). On the contrary, farmers can also consider that climate change is not occurring due to a lack of physical evidence (Abid et al. 2016b). Although most papers reinforce a dominant farmers' profile, some papers exemplify the diversity when characterizing farmers. For example, in the study by Arbuckle et al. (2013a) in the Midwestern United States, one-third of the respondents believed that climate change is caused by natural changes in the environment together with human activities, while another one-third of the farmers mainly focused on natural changes and the last third reports a lack of sufficient evidence to know if climate change is occurring and its causes.

Perceived impacts

Farmers' perceptions of long-term or short-term changes in climate are a crucial pre-indicator in the climate change adaptation process. Studies reported 13 significant climate change impacts considering their physical and agricultural nature (detailed in Online Resource 4). Among them, farmers mainly perceive three impacts conditioning farming activity: (1) rising and extreme temperatures, (2) changing rainfall patterns and unpredictable and erratic trends, and (3) increasing drought and dry spells. Most studies report an increasing trend in temperature and variability (e.g., Asfaw et al. 2019), especially over the last 15–20 years (e.g., Fosu-Mensah et al.

2012; Esham and Garforth 2013; Akhtar et al. 2019), while including a slight increase in temperature for both summer and winter seasons (e.g., Abbas et al. 2019). Likewise, other studies focus on identifying unpredictive temperature-related events (e.g., Bagagnan et al. 2019) that seem larger and more robust than those historically experienced (e.g., Niles et al. 2013). Furthermore, a reduction in the number of cold days and an increase in the number of hot days have been reported in a few studies (Tambo and Abdoulaye 2013).

Regarding changes in rainfall patterns, farmers perceive a strong decrease in rainfall over the last decade (e.g., Comoe and Siegrist 2015; Brussow et al. 2019) but also changes in frequency and length of rainy days and seasons (e.g., Tesfahun and Chawla 2020). Some studies discuss potential discrepancies between farmers' perceptions and meteorological observations of temperature and precipitation. For example, the study by Ochieng et al. (2017) in Kenya identifies a mismatch between farmers' beliefs and evidence of climate data: farmers perceive a decline in rainfall, despite no evidence in the climate data. According to the authors, this could be due to increasing temperature since high temperature often leads to higher evapotranspiration and greater water demand. However, other studies identify a match between farmers' perceptions and historical meteorological trends, especially regarding temperature increase and irregular precipitation patterns (e.g., Elum et al. 2017; Bacha et al. 2018).

The third most perceived risk (drought and dry spells) is directly related to the previous two (temperature and rainfall patterns) because the combination of persistent high temperatures and low rainfall periods is the main driver for drought risk, as reported in the study by Popoola et al. (2018) in South Africa. Similarly, Soglo and Nonvide (2019) determine from their experience in Benin that drought tends to occur every year during the crop production season due to decreasing rainfall patterns. Moreover, since agricultural yields are highly dependent on temperature and precipitation patterns, most farmers often blame an unfavorably changing climate for their decreasing yields and crop failures (e.g., Brussow et al. 2019), especially for maize, bean, and coffee farmers (e.g., Harvey et al. 2018). Additionally, most farmers detail an increase in pest and disease outbreaks (e.g., Fosu-Mensah et al. 2012; Shi et al. 2019) and soil-related problems, including soil infertility, soil salinity, and soil erosion (e.g., Abid et al. 2016b; Alotaibi et al. 2020; Aryal et al. 2020), leading to a reduction in the amount of organic matter and loss of rooting depth (e.g., Khan et al. 2020b) and increasing land degradation (e.g., Callo-Concha 2018; Kumasi et al. 2019).

Adaptation measures

Studies report 11 main climate change adaptation measures (Table 6 and further details in Online Resource 5), of which (1) changing cropping patterns, (2) introducing new crop varieties, and (3) promoting soil and water conservation techniques are the most applied. About half of the studies report examples of changing cropping patterns, including intercropping (e.g., Lawson et al. 2020), planting of short-term crops (e.g., Diallo et al. 2020), changing planting dates (e.g., Abid et al. 2016b), crop rotation (e.g., Fadina and Barjolle 2018), and crop combination (e.g., Ado et al. 2020). Likewise, studies highlight the introduction of new crop varieties more adapted to water scarcity (drought-tolerant crops) or new pests resulting from changing weather conditions (insect-tolerant crops) (Azumah

Table 6 Main adaptation measures organized according to different functions requested by farmers

Function	Measure
Ensuring crop production	Changing cropping patterns (e.g., Deressa et al. 2011; Alam et al. 2012; Abid et al. 2015; Bakhsh and Kamran 2019; Kumasi et al. 2019; Funk et al. 2020)
	New crop varieties (e.g., Deressa et al. 2011; Abid et al. 2015; Macholdt and Honermeier 2016; Al-Amin et al. 2019; Mutandwa et al. 2019; Paudel et al. 2020; Thangrak et al. 2020)
	Reduce cultivated area or livestock diversification (e.g., Comoe & Siegrist 2015; Bacha et al. 2018; Esfandiari et al. 2020)
	Organic fertilizers or pesticides (e.g., Alam et al. 2012; Abid et al. 2016a; Quan et al. 2019; Alvar-Beltran et al. 2020)
	Planting shaded trees (e.g., Deressa et al. 2011; Comoe & Siegrist 2015; Asayehegn et al. 2017; Hirpha et al. 2020)
	Purchasing agriculture insurance (e.g., Jin et al. 2015, Mase et al. 2015, Akinbile et al. 2018, Tesfahun & Chawla 2020)
	Migration to other (rural) areas (e.g., Ayanlade et al. 2017; Ferdushi et al. 2019; Amir et al. 2020a, b)
Improving natural resources management	Soil and water conservation techniques (e.g., Jin et al. 2015, Mase et al. 2015, Harvey et al. 2018, Orduño-Torres et al. 2020; Singh 2020)
	Frequent or supplementary irrigation (e.g., Deressa et al. 2011; Abid et al. 2015; Belay et al. 2017; Amamou et al. 2018; Nong et al. 2020; Wang et al. 2020)
	Water harvesting and infrastructures (e.g., Esham & Garforth 2013; Ochieng et al. 2017; Fadairo et al. 2020)
Guarantying income	Promote off-farm activities (e.g., Esham & Garforth 2013; Abid et al. 2016b; Ado et al. 2020)
	Partial/short-term migration to urban areas (e.g., Abid et al. 2016b)

et al. 2017). In their study in Bangladesh, authors such as Ferdushi et al. (2019) pointed out how crop diversification can be a compelling adaptation option to stabilize crop revenue and farm income. Frequently, crop diversification is accompanied by other measures such as planting shade trees to reduce soil moisture loss, as reported in the study by Esham and Garforth (2013) in Sri Lanka. Another complementary measure is extending cropping to the dry season to promote high-yielding hybrid crops and even long-duration crops, as reported by Tambo and Abdoulaye (2013) in Nigeria.

In some studies, such as Asfaw et al. (2019) in Ethiopia, the proportion of farmers who adapted to climate change is substantially less than those who perceive the incidence of a changing climate. However, although some studies report minor adaptation intention (e.g., one-third of the farmers in the study by Fahad et al. 2020 in Pakistan), in most studies, farmers had taken at least one adaptation strategy, even farmers developed various adaptation methods simultaneously (e.g., Funk et al. 2020), including the intensification of agricultural production by using more inputs, especially fertilizers, planting fruit and fodder tree, improving soil and water conservation practices, and using crop residues as livestock feed (e.g., Belay et al. 2017). For instance, farmers may change cropping patterns and crop varieties, which may require an increase/decrease in supplementary irrigation (e.g., Deressa et al. 2011). Farmers may also decide to change their occupation (switch to off-farm income) to earn additional income based on their livelihood (e.g., Marie et al. 2020) or to insure their crop in the event of crop failure through crop insurance (e.g., Fadairo et al. 2020; Singh 2020; Thinda et al. 2020).

Moreover, some studies distinguish adaptation measures considering their reactive or preventive nature. For example, the study carried out in Nepal by Budhathoki et al. (2020) reports the reactive nature of farmers during heatwaves, when they mainly apply better water management practices, alter fertilizer and pesticide use, and change crop types and planting dates, but as soon as the risk is overcome, they return to traditional practices. Similarly, some actions related to changing cropping practices or varieties are implemented by farm households in the short term but cannot be maintained in successive crop campaigns. For example, to cope with droughts in South Africa, as reported by Myeni and Moeletsi (2020) or in Ethiopia, as reported by Belay et al. (2017), or in response to more crop pest attacks on old varieties or to extreme maximum temperatures which are negatively affecting the growth of most productive varieties, as reported by Abid et al. (2016b) in Pakistan. Some adaptation options are applied given their long-term benefits to reduce risks, such as soil and water conservation techniques to avoid flooding risk by constructing small-scale irrigation dams (e.g., Gebru et al. 2020), adaptation to dry season farming by water stored for vegetable farmers (e.g., Sadiq et al. 2019), as well as improve soil moisture and organic matter retention in line with agroecological practices (e.g., Harvey et al. 2018).

Factors conditioning adaptation

Socio-demographic characteristics and land tenure are the main factors affecting farmers' motivation to adapt (Online Resource 6). Regarding farmers' profiles, most studies report age as statistically significant when considering climate change awareness and perceived risks. In this line, the study of Abbas et al. (2019) in Pakistan determines how older farmers are the ones who perceive climate risks and impacts more clearly, while the study of Alotaibi et al. (2020) in Saudi Arabia confirms how older farmers are also those with higher levels of beliefs regarding climate change occurrence. Likewise, Comoe and Siegrist (2015), in their study in Cote d'Ivoire, conclude that an increase in age significantly influences the adoption of new crop varieties with a short growing cycle, while young farmers more frequently adopt the crop association and intercropping techniques. Similarly, in their Ethiopian study, Belay et al. (2017) highlight that age increase is positively related to the decision to intensify agricultural inputs (e.g., fertilizers and pesticides use) but not highly related to the probability of the household adapting to climate change by tree planting.

Educational level significantly and positively influences the likelihood of the adoption of some adaptation strategies. For example, farmers with higher education are modifying crop varieties or changing the land area under cultivation (e.g., Esfandiari et al. 2020). Belay et al. (2017), in their study of Ethiopian farmers, identify how a unit increase in the number of years of education could increase by 2–3% of the likelihood of adopting crop diversification, change in planting date, and integrating crop with livestock production. An explanation would be that educated farmers are expected to be more inclined to adopt new technologies based on their awareness of the available climate change adaptation measures (e.g., Bagagnan et al. 2019).

Vulnerability to climate change tends to be gender-biased (e.g., Jin et al. 2015; Brussow et al. 2019), but some studies provide mixed findings asking whether adaptation strategies differ by gender. While some studies find no direct effect of gender (Lasco et al. 2016), others conclude that men and women choose different adaptation strategies (e.g., Soglo and Nonvide 2019; Aryal et al. 2020). For instance, Zhang et al. (2020) report that male farmers are more likely than female farmers to adopt a rotational grazing strategy. Authors suggest that this can be explained because men are more likely than women to access information about climate change and weather forecasts, increasing their adaptive capacity. Likewise, some studies identify how gender-related differences can be motivated by other socio-economic variables such as education (e.g., Afriyie-Kraft et al. 2020). The study by Hirpha et al. (2020) confirms that the likelihood of adapting to climate change in Ethiopia is higher for male-headed households than for female-headed households, mainly because of cultural and social norms.

Farm size mainly determines the decision to combine multiple strategies to cope with climate change. According to Fadina and Barjolle (2018), in their study in Benin, the larger the farm, the more farmers opt to combine several adaptation strategies: agroforestry and perennial plantation, crop-livestock diversification, or new crop varieties. Likewise, the study by Asrat and Simane (2018) in Ethiopia found that when the farm size increases by one hectare, the probability of adaptation by combining different cropping options increases by about 1% in the wet lowland and by about 15% in the dry lowland. Other studies focused on how farm size influences the type of adaptation. For example, Myeni and Moeletsi (2020) work in South Africa suggests that larger farms are less likely to adopt technical expertise adaptation in favor of traditional adaptation. The authors argue that this could probably be due to the labor-intensiveness and resource-intensiveness of the strategies. Thus, large farms require significant financial investments in labor and inputs, which can be financially unattainable.

The majority of regression tests also reveal that the household head's farming experience significantly and positively influence farmers' awareness of climate change. The study by Thangrak et al. (2020) in Cambodia concludes that farmers with more farming experience are likely to be more aware and to have a better understanding of climate change and farm-related decision-making. This fits well with the study by Ado et al. (2019) in Niger, in which an increase in farming experience by 1 year increases the likelihood of awareness by one unit. Similarly, more farming experience increases recommended agricultural practices and improves crop varieties (e.g., Aydogdu and Yenigun 2016; Kawadia and Tuwari 2017; Sadiq et al. 2019). In line with the study by Zhang et al. (2020), this implies that the higher the farming experience, the more the farmer will be aware of climate change and willing to adjust farming methods by acting on crops.

The land tenure system is vital to adaptation as landowners adopt new technologies more quickly than tenants. According to Roco et al. (2015), Chilean farmers with land tenure security exhibit a sharper awareness of environmental problems. Along the same line, in their study in Vietnam, Huong et al. (2017) report that farmer land tenure status is positively associated with most adaptation measures (e.g., water harvesting and infrastructures). According to the authors, farmers with long-term use rights of suitable land are more likely to adapt their farming to perceived climate change, reducing the probability of no adaptation to almost zero (Khan et al. 2020b).

Lastly, some studies confirm that union farm membership contributes to affront climate change impacts in a shared way, ensuring trust and confidence among the farmers (e.g., Aryal et al. 2020). Likewise, being part of a formal agricultural cooperative or association provides updated climate change information, improved agricultural inputs, and access to different farm equipment, which are crucial for increasing adaptation to climate change (e.g., Burnham and Ma 2017; Gebru et al. 2020). However, most studies are aware of the negative contribution of being member of a union farm. For example, Al-Amin et al. (2019) argue that farmers could receive misleading or contradictory climate change information or even ignore the existence of climate services to improve decision-making, while the study by Adzawla et al. (2019a, b) in Ghana determined that union farm membership did not substantially improve the farmers' recovery capacity and resilience from climate shock.

Adaptation barriers and constraints

About one in four papers ask about which obstacles limit farmers' ability to apply for adaptation measures. Farmers identify ten main barriers that hindered their adaptive capacity (Table 7 and Online Resource 7 for further details). The three major ones are (1) the lack of information on adaptation strategies and weather forecasting (confirmed by nearly two-thirds of the sample), (2) the lack of credit facilities and financial support to promote adaptation (according to half of the sample), and (3) the absence or poor irrigation expertness (reported by 40% of the sample). Interestingly, these three obstacles are combined in some papers (Ochieng et al. 2017; Zizinga et al. 2017; Ali et al. 2020; Marie et al. 2020). Authors such as Ochieng et al. (2017) and Esham and Garforth et al. (2020) identify a limited ability of farmers to access the necessary knowledge and technologies to adapt to the extreme effects aggravated by climate change. The explanation seems related to poor skills in improving farmers' practices and access to weather forecasts and climate change-related information. Sujakhu et al. (2020) consider that farmers require different climate information during each stage of the farming process to appropriately adapt to climate change and its related hazards, while the study by Fahad and Wang (2018) in Pakistan opts to combine different information sources (e.g., the media, technicians) and personal experience. However, farmers, and more specifically smallholders, sometimes fail to adapt, even when provided with adequate information, because they are resource-constrained and are conditioned by a lack of credit facilities or financial support (e.g., Alemayehu and Bewket 2017; Zizinga et al. 2017). According to Sujakhu et al. (2020) or Zhang et al. (2020), with more financial resources, farmers are better able to use the available information to improve their management practices and make productive investments (e.g., they can purchase new crop varieties and irrigation technologies that are necessary for adjusting to climate changes or diversifying their livelihood and income sources).

Table 7 Main barriers limiting farmers' adaptive capacity according to different categories

Type	Barrier
Farmers' profile	Low literacy rate (e.g., Belay et al. 2017; Bagagnan et al. 2019)
	Small size of landholdings (e.g., Sadiq et al. 2019; Amir et al. 2020a)
	Poor land access and ownership (e.g., Lawson et al. 2020; Marie et al. 2020)
	Economic cost of adaptation (e.g., Zizinga et al. 2017; Akhtar et al. 2018, 2019)
Facilities and services	Lack of credit facilities and financial support (e.g., Tambo & Abdoulaye 2013; Ochieng et al. 2017; Rondhi et al. 2019; Sujakhu et al. 2020)
	Absence of irrigation expertness (e.g., Alemayehu & Bewket 2017; Tesfahun & Chawla 2020)
	Lack of extension services (e.g., Fosu-Mensah et al. 2012; Esham & Garforth 2013; Kumasi et al. 2019)
Support and information	Lack of information on adaptation strategies and weather forecasting (e.g., Arbuckle et al. 2013a; Tambo & Abdoulaye 2013; Fahad & Wang 2018, Hasibuan et al. 2020; Iqpal et al. 2020)
	Lack of or insufficient government support (e.g., Sulewski and Kloczko-Gajewska, 2014; Akhtar et al. 2019)
	Lack of agricultural inputs (e.g., Fosu-Mensah et al. 2012; Abbas et al. 2019)

The absence or the inadequacy of irrigation expertness are reported in studies carried out in Pakistan (e.g., Amir et al. 2020a) and Iran (e.g., Esfandiari et al. 2020), suggesting that the lack of mechanisms to better control both water allocation and water efficiency constrain farmers' adaptive capacity, especially in some cropping systems (e.g., wheat and rice). The cost of current water conservation techniques is also mentioned, which is not always affordable for most farmers (e.g., Bagagnan et al. 2019). In most cases, this is associated with the inability of farmers to use both surface and groundwater due to limited technological and financial capacity (e.g., Ali et al. 2020). Moreover, some authors consider low literacy rates and lack of education as secondary barriers to adaptation (e.g., Belay et al. 2017; Bagagnan et al. 2019). Likewise, some barriers are different considering the gender dimension. For example, the study by Assan et al. (2020) on Ghanaian farmers highlights how women worry more about the lack of information and financial support than men, while men identify poor irrigation expertness as the main barrier to adaptation.

Discussion and further research

Climate change tends to be addressed by accurate statistics and modeling but it is generally perceived abstractly, differing from other hazards because it occurs gradually, over an extensive period, being difficult to directly discern changes as they occur (Weber 2016). Furthermore, climate change observations are spaced in time, and individual and collective memory of past events can be faulty or uncertain (Song et al. 2021), distinguishing between knowing facts (semantic) versus reliving events or experiences (episodic) (Plate 2017). Considering climate change as both a physical and social phenomenon, farmers' knowledge and local experience is becoming more relevant to ensure reliable attitude change and increased adaptation. A better understanding of farmers' behaviors is indeed fundamental to promoting accurate actions as it allows (i) focusing on the specific behaviors to be changed, (ii) examining the driving factors motivating those behaviors, (iii) defining and applying different interventions, and (iv) systematically evaluating the effects of these interventions on the resulting farmers' behaviors.

Our study attempted to systematically examine the literature on farmers' behavior by combining a triple-loop approach on risk awareness, perception, and adaptation. The review elicited how the research on climate change awareness, perceived impacts, and adaptation measures and barriers is fast-growing and illustrates an inherently multifocal research topic. A comprehensive BA pointed out research collaboration (e.g., high level of co-authorship) from a transdisciplinary perspective beyond climate change issues (e.g., sustainable development, natural resources management, urban–rural land use). Works included in the cluster led by J. Gordon Arbuckle Jr. and colleagues (e.g., Arbuckle et al. 2013a, 2013b, 2015), who pointed out farmers' beliefs and perceived risks in the USA, exemplified this issue. Likewise, rapid growth in the publication ratio (85% of articles produced in the last 5 years) and an increasing number of global citations demonstrated main consolidated research areas related to climate change impacts (e.g., reduce on food production, crop vulnerability) and adaptation measures (e.g., crop choice), while new concepts (e.g., techno-optimism, science-truth) appeared to deal with extreme weather events (e.g., Gardezi and Arbuckle 2019, 2020) by prioritizing climate-smart agriculture (Gardezi et al. 2022). Thematic analysis and clustering confirmed a dichotomy in the research interest generated by the triple-loop dimensions: while "adaptation" was considered as a motor theme, structuring the research field, "perception" and "awareness" were partially considered as sub-themes, that is, being included in the basic theme "climate change" but without enough attention to be a niche or emerging theme. A recent review by Ricart et al. (2022) confirmed the low occurrence rate between climate change perception and awareness research in benefit of adaptation research. Moreover, previous research demonstrated how farmers' awareness combined with an accurate perception is imperative to scale farmers' ability to mitigate the effects on farming activities and as a preliminary step to increase adaptive capacity (Akano et al. 2022; Sen et al. 2021).

The SLR analysis delved into main themes isolated during the BA by highlighting farmers' local experience from main topics, driving factors, motivations, and barriers when facing climate change. The first interesting point was the ability of multiple sociodemographic characteristics to influence farmers' behavior regarding climate change: age, gender, education, farming experience, and farm size have been identified as key issues in understanding farmers' adaptive capacity. Furthermore, it was possible to identify a dominant farmer's profile from the analysis of the empirical research: a man of 40–50 years old, illiterate or with primary education, counting more than 10 years of farming experience, and working with a farm size between 5 and 10 ha. This profile confirms that most farmers have been farming in the area for quite a long time and therefore they could witness changes in temperatures and rainfall patterns (Mbwambo et al. 2021). Likewise, results show how oldest, highest educated, and most experienced farmers are the most aware of climate change occurrence, those who perceive more impacts, and who are more confident with adaptation measures to deal with climate change, while gender and farm size influence the way of adaptation but not the degree of agreement with climate change occurrence, perceived impacts, and need for adaptation.

The review upholds key interactions between farmers' characteristics and behaviors regarding climate change awareness, perceived impacts, and adaptation measures and barriers (Fig. 6). Field observations support how farmers are primarily aware of climate change, which is considered the most challenging issue with direct effects on crop productivity, while they recognize human activities' responsibility (including agricultural activity) in global warming. Some studies moved one step further and suggest that awareness, combined with local knowledge, are the main prerequisites for (smallholder) farmers to perceive climate change impacts and adopt adaptation strategies (e.g., Myeni and Moeletsi 2020; Roesch-McNally et al. 2020). Interestingly, and in line with recent studies by Reddy et al. (2022) and Sohail et al. (2022), the systematic review confirms that farmers' awareness of climate change occurrence and severity is more robust than that of the causing factors of climate change. The review also identifies a common

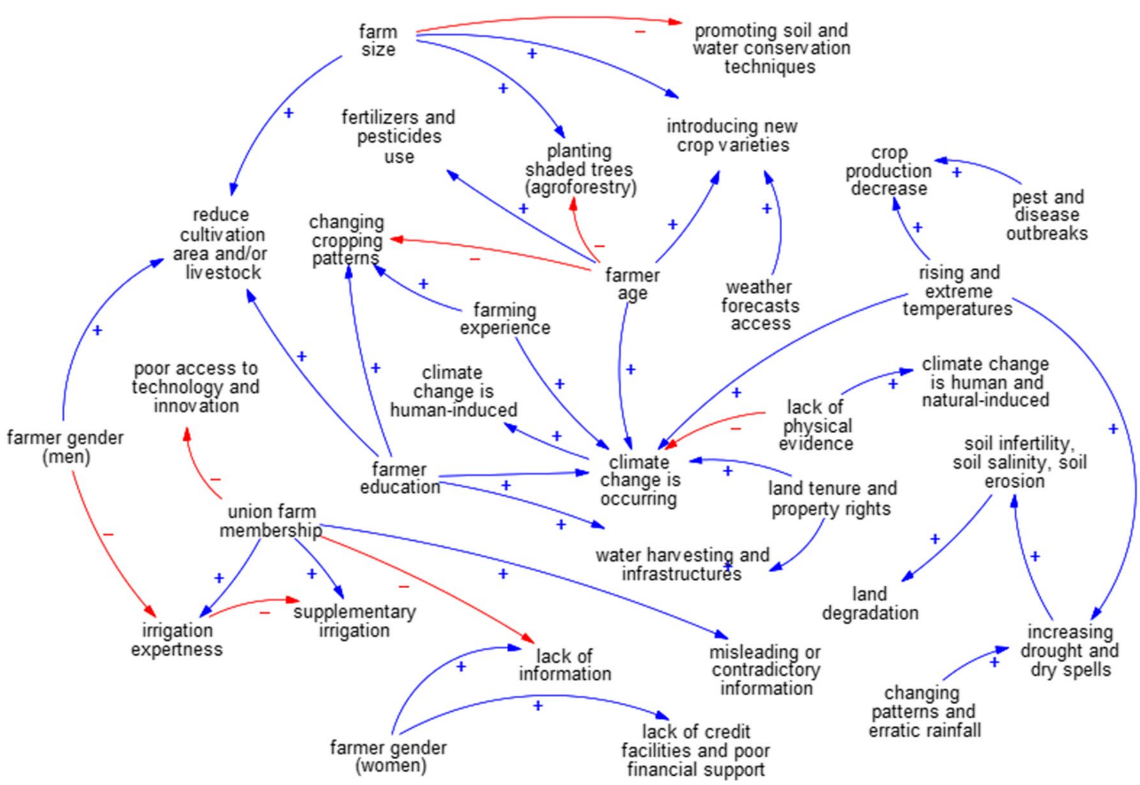

Fig. 6 Causal-loop diagram graphing key interactions between farmers' characteristics and behavior and climate change awareness, perceived impacts, and adaptation measures and barriers. Methodological notes: Only interacting factors from the literature have been considered. The causal polarity between factors is described in blue color for positive (+) interactions if the variables change in the same direction or in red color for negative (–) interactions if they change in the opposite direction

pattern to describe the main perceived impacts compared to those historically experienced, in which local knowledge was used in conjunction with scientific knowledge systems from meteorological data analysis (e.g., Ayanlade et al. 2017; Alvar-Beltran et al. 2020). Most of the reported case studies analyze both physical and agricultural impacts of climate change, although with greater detail on the first. Farmers noticed physical impacts such as rising extreme temperatures, changing rainfall patterns and erratic trends, and increased droughts frequency and/or intensity, whereas perceived agricultural impacts are limited to reducing crop production, increasing pests and diseases, and conditioning soil fertility combined with land degradation. Furthermore, some studies reported both types of impacts to delve into a causal relationship among them (e.g., Roco et al. 2015; Elum et al. 2017; Abbas et al. 2019; Ado et al. 2020).

Farmers promote adaptation measures capable of reinforcing crop production (e.g., changing cropping patterns, introducing new crop varieties) and improving natural resources management (e.g., promoting soil and water conservation techniques). However, as confirmed by a recent study (Paudel et al. 2022), some adaptation options are resource-intensive (e.g., fertilizers and agrochemicals use, water harvesting and infrastructures, supplementary irrigation), being inaccessible for smallholder farmers with limited capital or no access to financial support, which has been observed in most African and Asian case studies in which lack of credit facilities was the main barrier to adaptation (e.g., Bacha et al. 2018; Marie et al. 2020). To face this limitation, some authors (Abebe et al. 2022) advocate strengthening the comprehensive knowledge of the states of farmers' adaptation by considering current and planned farm adaptation practices. Furthermore, and considering the nature of the reviewed studies in which farmers' vulnerability is at the core of the research, attention should be put on the best cost-effective actions to ensure an effective rural and climate policy action to respond to evolving climate risk. In this line, authors such as Aleksandrova and Costella (2021) and Rana et al. (2022) advise reinforcing the social protection agenda to tackle the issues of poverty, inequality, and vulnerability, which should be integrated into comprehensive climate risk management practices.

The content analysis also reported that most explanatory factors for farmers' awareness, perceived risks, and adaptive capacity are common among geographically distant case studies. The triple-loop dimensions are not geographically sensitive, meaning global climate change effects are perceived as locally relevant. This could be used to homogenize social learning from a local scale while checking common and replicable assessments to improve farmers' adaptive capacity (Schlosberg and Collins 2014). However, the sample is not geographically representative. Although high-income countries perceived climate change impacts more clearly than ever before (Callaghan et al. 2021), a low representation of Global North-based literature has been identified, with a ratio of 1 to 9 in favor of Global South studies. Most studies focused on African and Asian countries (96 of 108 articles), both regions in the top 10 most affected areas by climate change according to the Global Climate Risk Index in 2020. This ratio enhances a recent literature review by Soubry et al. (2020) in which the proportion was 1 to 6. According to the mentioned authors, Global North studies tend to emphasize farmers' characterization rather than how they perceive or react to climate change. Likewise, and concomitantly, the fact that farmers in the Global South have generally suffered first and more strongly (including forced migration) from climate impacts due to their consideration of climate change hotspots might bias the research interest towards the former region (Piguet 2022).

Another outcome of the review is the cross-sectional nature of the analyses (e.g., one-off surveys, interviews, or focus groups at a point in time). Although some sampled studies combine multi-stage techniques (e.g., Adzawla et al.2019a; Aryal et al. 2020) and different data collection tools (e.g., Asayehegn et al. 2017; Ado et al. 2020), in general, it remains unexplored how farmers' awareness, perception and adaptation evolve. That is, farmers' beliefs can differ some years later (e.g., due to the occurrence of new extreme events or after consolidating the use of climate services) and eventually guide different attitudes and motivate alternative behaviors (Sierra-Barón et al. 2021). Consequently, there is a need to shift research efforts from the point in time to over-time studies by using a panel approach (repeated surveys to the same farmers or similar profiles as representative) that could provide better information to close the farmers' feedback loop. A recent study by Wheeler et al. (2021) employed panel data (following the same farmer over 5 years) to examine climate change perceptions' influence on-farm adaptation. Results show that farmers who initially thought climate change imposed a risk had a higher propensity to apply more prudent farm practices, which subsequently decreased their climate risk perceptions after 5 years (and vice versa). Authors such as Dakurah (2021) suggest analyzing climatic data beyond inter-seasonal climatic events to include intra-seasonal climatic episodes as the latter are more critical to farmers: within every season, farmers are worried about when rain will start, how long will the season last, or if dry spells will occur. Likewise, it could be helpful to introduce past experiences in extreme events as examples of inter-seasonal climatic episodes to reduce farmers' psychological distance to climate change and increase attitude change (Datta and Behera 2022).

We are aware of some limitations of our study, especially concerning data collection. Although an extensive sample has been used to carry out the BA and the SLR, the selection criteria were limited to scientific articles, excluding additional scientific documents (books, chapter books, reports, academic studies, etc.). Consequently, some publications providing empirical and local knowledge to reinforce foundational theories on farmers' behavior regarding climate change have not been considered. Likewise, the sample was limited to English-speaking sources, which leaves out relevant contributions in other languages widely used to collect data at the local scale. Furthermore, the review targeted the survey results while complementary information from semi-structured interviews or focus groups remained in the background.

Considering the main results obtained from the BA and the SLR, and to face the limitations of the review, we suggest future research could explore three main questions: (1) Which socio-demographic characteristics are conditioning farmers' climate change perceived impacts and how can they be analyzed in depth? (e.g., How characteristics can be synthesized in surveys to compare farmers' profiles? Could other data collection tools such as semi-structured interviews or focus groups complement surveys' feedback?); (2) How farmers' awareness, perceived impacts, and adaptive capacity have evolved and how stable they are (e.g., Does longitudinal research ensure more robust farmers' attitudes? Which drivers can destabilize farmers' perception?); and (3) Is farmers' behavior associated with the (in)existence of mitigation and adaptation strategies at regional and local scales? These three-fold questions could also facilitate the application of the Theory of Planned Behavior as the combination of the "antecedent or information" approach (i.e., internal drivers explaining farmers' attitudes) with the "consequence or structural" approach (i.e., contextual factors encouraging farmers' attitude change) (Masud et al. 2016). Consequently, a transdisciplinary investigation can further explore how farmers interact with climate change. For example, social sciences (e.g., Sociology, Psychology, and Geography) could identify the main social aspects influencing farmers' behavior. In contrast, natural sciences (e.g., Agronomy, Earth Science, Geology, and Engineering) could produce more accurate climate change scenarios and projections in which risks and impacts will be easily identifiable by farmers.

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Data Availability The dataset reviewed during the current study are available in the reference list and characterized in the supplementary sources.

Declarations

Competing interests The authors have non-financial interests to disclose.

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