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REVIEW

Correlations between climate resilience in family farming and sustainable rural development

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Abstract Given the recognition that climate change predominantly affects the most vulnerable groups, there has been a growing interest in reorientations that can influence family farming's resilience. However, there is still a lack of research relating this subject to sustainable rural development perspectives. We reviewed 23 studies published between 2000 and 2021. These studies were systematically selected according to the pre-established criteria. Even though there is evidence that using adaptation strategies can effectively strengthen climate resilience in rural communities, many limiting factors remain. The convergences for sustainable rural development may include actions with a long-term horizon. These actions include an improvement package for territorial configurations within a local, inclusive, equitable, and participatory perspective. Furthermore, we discuss possible arguments for the results and future directions to explore opportunities in family farming.

Keywords Adaptation strategies · Climate emergency · Rural family system · Sustainability · Territorial development

INTRODUCTION

Studies regarding climate change's influence on agriculture are steadily becoming more robust. Besides representing more than 80% of rural areas, small farms worldwide are characterized by household subsistence, food supply, and local trading activities (Ploeg 2014; UNESCO 2019).

In this context, family farming can neither escape its economic, social, and environmental context, nor reduce its role in local development, including income generation, healthy food supply, or water, soil, and biodiversity preservation, for example (Schneider 2016; Thies et al. 2022). The diverse configurations, not only as a way of life but especially for their agricultural diversification, history, and traditions, are assumed here as polysemic and supporting elements of sustainability (Carniatto 2007). In recent years, these characteristics received focus due to the impacts and conditions faced in light of climate change as more recurrent obstacles.

It is worth noting that despite technological advances, agriculture is highly dependent on natural environmental conditions, including climate (Dhanya et al. 2022; Santos et al. 2022). However, few efforts have explored the negative effects of climatic impacts on rural communities, which makes in-depth knowledge in this area limited (Schneider 2016; Ginbo et al. 2021).

In family farming, climate change is specially more salient in developing countries. However, the influence of climate change has social, economic, technological, and other implications limiting the development opportunities, which causes unprecedented and incalculable damage to agricultural production, increased poverty, territorial conflicts, and hunger in many regions (FAO 2017; Shimada 2022). Given the natural resource degradation and the need to find efficient, sustainable alternatives to adapt to climate change in rural areas, this study focuses on climate resilience and its conjuncture in family farming areas.

In general, climate change constitutes a global conceptual problem and practical complexity. It involves many challenging conditions felt by several ecosystems and human communities, requiring constant reflections regarding the most vulnerable groups (Lampis et al. 2020).

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Climate change is especially due to intensive human exploitation of natural resources, which fosters an unsustainable development model, resulting in scenarios involving emissions of greenhouse gases, aerosols, and other precursors, biodiversity loss, changes in land use, and excessive profiteering in most countries (Artaxo 2020; IPCC 2021). Climate change results in extreme weather events, such as heatwaves, intensification of the water cycle, including extreme droughts and floods (IPCC 2021).

Changes in the intensity and periodicity of climate-influenced natural disasters have increased worldwide. Natural disasters caused by the advance of global climate change have many possible impacts on agricultural areas. They have been investigated as a potential trigger for the lack of resilience in urban and rural communities. Nonetheless, although they are recognized in their magnitude, they are not currently incorporated into the themes embedded in the sustainable rural development perspective. When considering the numerous challenges imposed, climate resilience presupposes that regardless of the farming approach adopted, living with the transformations requires new reorientations in living and producing.

This research adopted the climate resilience concept as an observed or perceived ability in systems and their components and as an efficient response to extreme environmental factors, capable of sustaining the maintenance of basic and essential conditions (IPCC 2021). Therefore, within the family farming system, it covers the various aspects affecting these units such as the increase in pests and diseases, making it impossible to grow plants and compromising the family income, for example, and the system's ability to overcome such effects, both individually and collectively.

One way to improve resilience in rural communities is to incorporate new notions of productive rural practices, and research on information diffusions, innovations, infrastructure, and technologies, for example (Nicholls and Altieri 2019; Milhorance et al. 2021). Such structures express the idea that other strategies must complement climate resilience and involve a broad set of dynamically effective policies. As pointed out by Folke et al. (2021) and Torres et al. (2021), resilience is a complex challenge because of the biggest shift in viewpoint, plans, and actions needed to support its construction. In this context, climate resilience includes efforts articulate to the establishment of climate commitments at the public policy level—to achieve a more insurgent, just, and transformative world sustainability.

Thus, it is important to contemplate the impacts of global climate change for agriculture (Ginbo et al. 2021) especially for family farming, since its effects may further limit the conditions required for food production and farmers' livelihoods (FAO 2019; Tiet et al. 2022). Considering the alarming predictions regarding future climate changes, in-depth pathways to tackle and understand the complexity of climate change dynamics are urgently required (Thompson-Hall et al. 2016; Malhi et al. 2021; Carmen et al. 2022).

While there are fruitful discussions regarding strategies for strengthening the structure of long-term rural resilience through different experiences, little attention has been paid to the agglutination of different sustainability factors in rural development. Moreover, it is unclear what paths can be pursued to advance the construction of a more sustainable society, able to live and ensure agricultural production within planetary boundaries (Abbass et al. 2022).

There are some literature reviews on climate change in agriculture and its mitigation strategies (Malhi et al. 2021; Marengo et al. 2022) and in relation to sustainable management of water resources (Srivastav et al. 2021). However, yet there is a knowledge gap about the intersections used to describe climate resilience in agriculture at the household level, the concept of sustainable rural development, and other elements related to addressing this reality.

Thus, as an initial step to gather such information, this study aimed to review the literature regarding the family farmers' resilience to climate change to promote sustainable rural development, based on the analysis of scientific papers published worldwide between 2000 and 2021.

In this study, we address the following three research questions:

- Do the literature describe the understanding of the opportunities and challenges for family farming in the climate change context?
- What adaptation actions have been described to improve climate resilience in agricultural systems?
- What possible indications of climate resilience dynamics and synergies in family farming have been addressed?

To achieve the research objective, we conducted a scoping review and applied the standards of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol and Discursive Textual Analysis (DTA). Based on these criteria, we describe the resilience challenges to family farming, providing an understanding of the opportunities and adaptations. Combining the emerging categories in the qualitatively analyzed texts forms a thematic cut-out with four elements to broaden climate resilience structure in the rural system.

This study is primarily focused on family systems. A scope with elements is presented that provide researchers and policymakers with integrated directions to enhance the climate resilience framework in rural communities.

METHODOLOGY

To explore aspects of climate resilience in family farming and its cohesion to sustainable rural development, we conducted a scoping review in the literature. This method is suitable for mapping state of the art, filling knowledge gaps, and identifying available factors and evidence on a given topic (Arksey and O'malley 2005; Munn et al. 2018). The literature review allowed the synthesis of the existing literature and is useful because it makes the prominence of the theme explicit to the reader. According to Holmgren et al. (2020) scientific publications are an excellent principle for exploring any area of research.

The literature reviewed was from 2000 to 2021, based on the recommendations of the PRISMA protocol, which comprises three main steps: identification, screening, and inclusion (Page et al. 2021). The period was chosen because areas of research linked to climate change have gained pace since 2000, as researchers grappled to discover how climate change would impact different sectors. We also applied the DTA method to the selected studies to analyse content to answer the research questions.

Identification, eligibility, and screening criteria

The literature review was conducted using six online databases, namely: (i) Brazilian Digital Library of Theses and Dissertations (BDTD); (ii) Journals Portal of the Coordination for the Improvement of Higher Education Personnel (CAPES); (iii) Web of Science; (iv) Scopus; (v) Directory of Open Access Journals (DOAJ); and, (vi) Scientific Electronic Library Online (SciELO). These databases were selected because they present a wide range of publications worldwide, in the various areas of the scientific field.

In addition to scientific articles, searches were also conducted in the gray literature, considering doctoral dissertations and master's theses. The search strategy consisted of four groups (see Supplementary information Table S1) of idioms in Portuguese, English, French, and Spanish, in combination with each other, without quotation marks, using the Boolean operator 'AND'. Materials were collected in January 2022, using descriptors 'resilience', 'climate change', and 'family farming'. The use of synonyms for the term 'climate change' and 'family farming' was also applied because the words may differ in the databases. In this case, 'climate emergency' was employed in all four languages mentioned above, and 'family agriculture' in English.

The initial identification was made by reading the titles and subtitles, abstracts, and keywords, considering for this review those that presented at least one of the descriptors in these elements. Then, the selective screening focused on studies whose content corresponded to this study's objective. In other words, those that brought the following aspects related to climate resilience in family farming: adaptation to and mitigation of climate extremes, policy instruments, challenges, opportunities, agricultural interventions, and water resource management.

In addition, a full analysis conducted on a thorough reading of the full texts prioritized primary studies focused on strategies and prioritization of actions for family farming regarding sustainable development promotion, identifying environmental, social, or political elements affecting the climate resilience of rural communities, and studies addressing limitations faced worldwide.

The excluded texts were those in duplicate, book chapters, abstracts of scientific events, literature reviews, in other languages, and unavailable in full at the time of collection. In addition, studies specifically related to gender, youth, food security, experimental techniques applied to agricultural sciences, animal and plant species resilience, biogeochemistry, meteorology, the Covid-19 pandemic, indigenous, and coastal communities were excluded due to their particular approaches and related contexts.

In the six online databases surveyed, 705 studies were identified using systematic search strategies (see Supplementary information Table S2). In the primary exclusion performed only by screening the titles, 35 duplicate studies were removed, and one was removed for being in a language different from those established in the criteria. When reviewing the titles and subtitles, abstracts, and keywords of the remaining 669 studies, a total of 590 were excluded for not having at least two descriptors in the titles/subtitles, abstracts, and keywords and for being book chapters, abstracts from scientific events, and literature reviews.

A full reading was performed on the remaining 79 studies. In this step, 38 others were excluded for not being available to download in full, presenting secondary data, or dealing with other themes. In the last screening step, 18 of the 41 studies were excluded because they presented approaches not aligned with this study's objective (see Supplementary information Table S3). Common reasons for exclusion included a lack of data on the family farming system's resilience to climate change, comparing geomorphological characteristics of agroecosystems, or unclear descriptions of the studied variables. For example, the research addressed resilience to urbanization, specifically focusing on training programs and collective health issues. The PRISMA flow chart (Fig. 1) shows the details. A total of 23 scientific studies were included in this review (see Supplementary information Table S4). All of them met the established selection criteria.

Data synthesis and analysis

The data collected from the studies provided crucial information for the analysis. The selected studies were

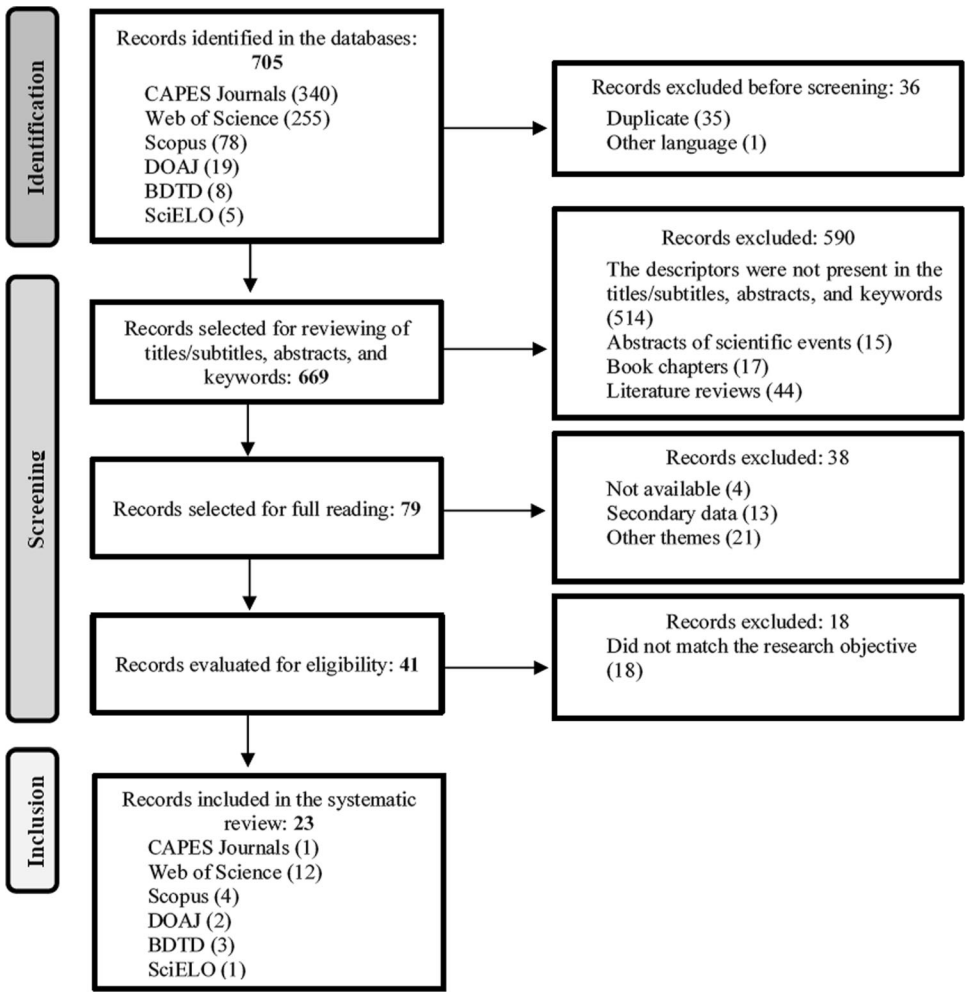

Fig. 1 Flowchart presenting the PRISMA protocol adopted in the scoping literature review on climate resilience in family farming

imported into MAXQDA® Pro 2022 software to assist in organizing and qualitatively analyzing the data. The data analysis followed the DTA technique described by Moraes and Galiazzi (2014), which comprises a creative process. It provides the construction of new meanings and the critical assimilation of the analyzed phenomena. This type of analysis challenges the researcher to broaden the subject's horizon.

The DTA technique is anchored in three self-organized steps. The first is the unitarization of the text corpus. It is a process that involves deconstructing the main discourses of the texts into units comprising similar contents. The second step includes categorizing the units. Based on an intuitive and inductive process, this categorization groups the units by reorganizing them according to similarity. This step involves the narrowing down of the categories. The third step includes communication. It comprises the metatext's development, expressing the researcher's understanding of the research findings. It can be presented at the researcher's discretion and reveals original directions and meanings regarding what was identified throughout the study (Moraes and Galiazzi 2014). The latter is the result of the interaction between the final categories, the study's objective, the capture and communication of a new emergent, which are presented in the results, as indicated in this qualitative analysis method. The DTA stands out in the hermeneutic field as a refined contextual interpretive movement. This analysis's main advantage is its cyclicality and the production of new insights (Souza and Vieira 2022).

Thus, the studies' analysis was initially conducted using the 'code highlighted document' function within the software to establish the disassembly of the text corpus by marking the excerpts related to the research objective and examining them in detail. Then, they were reorganized into major themes or initial categories by the 'new code' function for further analysis. To analyse the data, we organized the relevant discourses, and distributed in codes involving demographic challenges, rural poverty, environmental risks, social participation, and others. Moreover,

this reorganization established associations between the highlighted textual elements. It was based on identifying the intermediate and final categories, which were systematized using the 'abstracts with coded segments' function. After identifying the emerging categories, a refined reading was conducted to link connections with the study's objective and build the metatext, the phase of communicating the new understandings generated, as recommended in this technique. The last result section includes a specific topic detailing the metatext. Two researchers in this field performed data analysis and organized it around the research objective. The disagreements were resolved through discussion.

Figure and charts preparation

The quantitative data were extracted, prepared, and analyzed using simple statistics into Microsoft Excel software. The world map was created using the QGIS software (version 2.18) to represent the geographic distribution of the included studies.

RESULTS

Research attention on the confluences of climate resilience in family farming under several contexts and types of perspectives for sustainable rural development increased especially in 2020 (Fig. 2). No studies published before 2013 met the inclusion criteria. More than half of the included studies (n = 16) were published between 2018 and 2021. Although with oscillations, there is a growth in publications in the area. The concept of climate change is addressed across different fields. However, according to Ahmed et al. (2021) recently converged with potential impacts on the agricultural production system and how producers respond to climate change with it.

Discussions within this scope have occurred more frequently in recent years because the potential for climate change damage has been evolving. It has incorporated new meanings (Ali 2021; Keshavarz and Moqadas 2021), not only on the environmental issue, but emphasized as a convergence of justice aspects, in the diversity of contexts, production activities, and vulnerable populations, such as family farming (Lindoso 2013; Guyot 2018; Oyebola et al. 2021).

All of the included studies focused on rural areas and involved a total population of approximately 6.165 people. Of those 23 studies, 10 used qualitative methods, seven used quantitative methods, three did not clearly state the methodological approach, and three reported a combination of qualitative and quantitative data. A total of 20 studies were published in peer-reviewed scientific journals in different regions (Table 1).

The other three documents came from grey literature, with research developed in strictu sensu graduate programs, consisting of one master's thesis and two doctoral dissertations. The data collection was in four states: Rio Grande do Norte (Andrade 2013), Ceará, and Pernambuco (Lindoso 2013), and Bahia (Guyot 2018)—Brazil (n = 3), both in the semi-arid region.

We found that the 23 included records presented a range of approaches and have been reported on American, African, Asian, and European continents (see Fig. 3).

The included studies investigated challenges to resilience providing elements important to rural family succession (Guyot 2018), farmer perceptions (Mamun et al. 2021), agricultural diversification (Asmare et al. 2019;

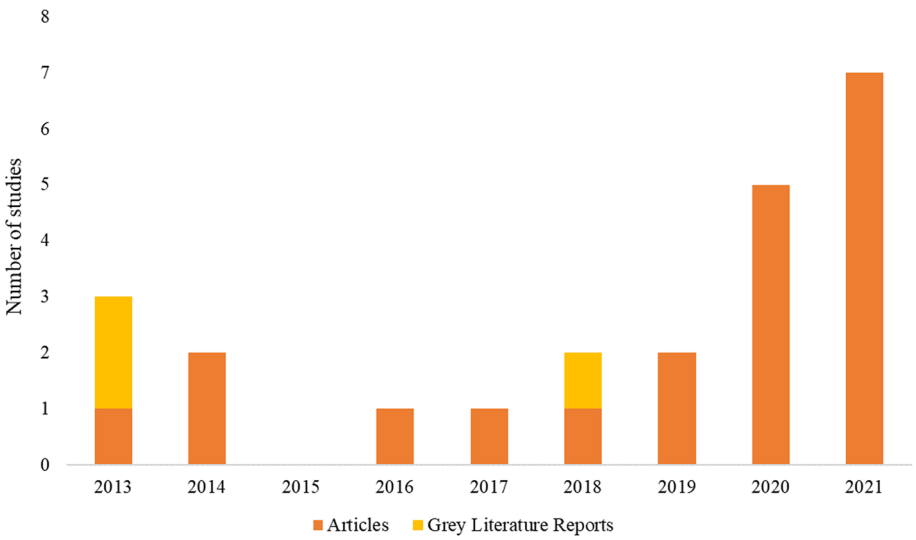

Fig. 2 Evolution of research interest on the topic of the family farmers' resilience to climate change

Table 1 List of reviewed scientific articles according to country and region of collecting data

Country	Region	References
Iran	Fars province	Karimi et al. (2017)
	Zagros region	Zarei et al. (2020)
	Khorasan Razavi province	Keshavarz and Moqadas (2021)
Ethiopia	Nile basin	Asmare et al. (2019)
	Wolaita zone	Bedeke et al. (2019)
	Tigrai state	Gebru et al. (2020)
United States of America	Chatham County	Bulla and Steelman (2016)
	Indiana, Michigan, and Ohio states	Valliant et al. (2021)
Bangladesh	Raydas Bari Char	Ahmed et al. (2021)
	Kurigram and Lalmonirhat districts	Mamun et al. (2021)
Burundi	Kirundo Province	Minani et al. (2013)
Colombia	Gómez Plata, Yolombó, Santa Rosa de Osos, Santo Domingo, and Amalfi municipalities	Turbay et al. (2014)
Bolivia	Alto Beni municipality	Jacobi et al. (2014)
Philippines	Negros Occidental province	Heckelman et al. (2018)
Pakistan	Punjab province	Naqvi et al. (2020)
France	Brittany, Aveyron and the Normandy	Perrin et al. (2020)
Ghana	South Tongu and Zabzugu districts	Zakaria et al. (2020)
Togo	Tone, Kpendjal, Tandjouare, Keran, Doufelgou, Kozah, Sotouboua, Tchamba, and Blitta districts	Ali (2021)
India	Arunachal Pradesh Meghalaya, Tripura, Assam, Manipur, Sikkim, Nagaland, and Mizoram states	Bhalerao et al. (2021)
Uganda	Kibuku and Gulu districts	Oyebola et al. (2021)

Perrin et al. 2020; Ali 2021; Valliant et al. 2021), adaptations and knowledge exchange opportunities (Minani et al. 2013; Turbay et al. 2014; Karimi et al. 2017; Bedeke et al. 2019; Naqvi et al. 2020; Zarei et al. 2020; Ahmed et al. 2021; Bhalerao et al. 2021; Keshavarz and Moqadas 2021; Oyebola et al. 2021), renewable energy (Bulla and Steelman 2016), water scarcity (Andrade 2013; Lindoso 2013; Gebru et al. 2020), agroecology (Guyot 2018), climate change capacity-building programs (Zakaria et al. 2020) and organic production (Jacobi et al. 2014; Heckelman et al. 2018).

Despite these various approaches only Andrade (2013) and Guyot (2018) directly mention the term 'Sustainable Rural Development'. The other 21 studies describe issues associated with the conceptual approaches and principles advocated in this field, such as 'agricultural sustainability', 'sustainable agricultural systems', 'sustainable farm management', 'sustainable system', 'sustainable production', 'sustainable development' or 'sustainable farming'. These results indicate the need for further research to explore the concept of Sustainable Rural Development and its role in addressing climate change.

In addition, most studies made recommendations for public policies for rural climate resilience or climate risk management at the local level (Table 2). This finding implies the need to formulate structured local proposals and formal programs to support different significant actions and initiatives to emerging climate issues and environmental changes. This suggests, ensuring convergences can be engaged in advancing agriculture production based on sustainability that considers the economic, social, political, environmental, and other aspects, to explore new opportunities and overcome challenges in the rural communities related to climate change.

Challenges and opportunities for family farming in the climate change context

The 23 studies identified in this review linked priority elements for climate resilience in family farming. However, some recommended the need to improve organized and efficient local commercialization and production networks that are not limited to technical and socioeconomic motivations, but that assist family farming in establishing sustainable mechanisms of cultivation, livelihood, and participatory action (Andrade 2013; Lindoso 2013; Minani et al. 2013; Jacobi et al. 2014; Heckelman et al. 2018). Those external efforts should be multilateral to strengthen and make sustainability policies flexible, applicable, and oriented to the rural communities demands.

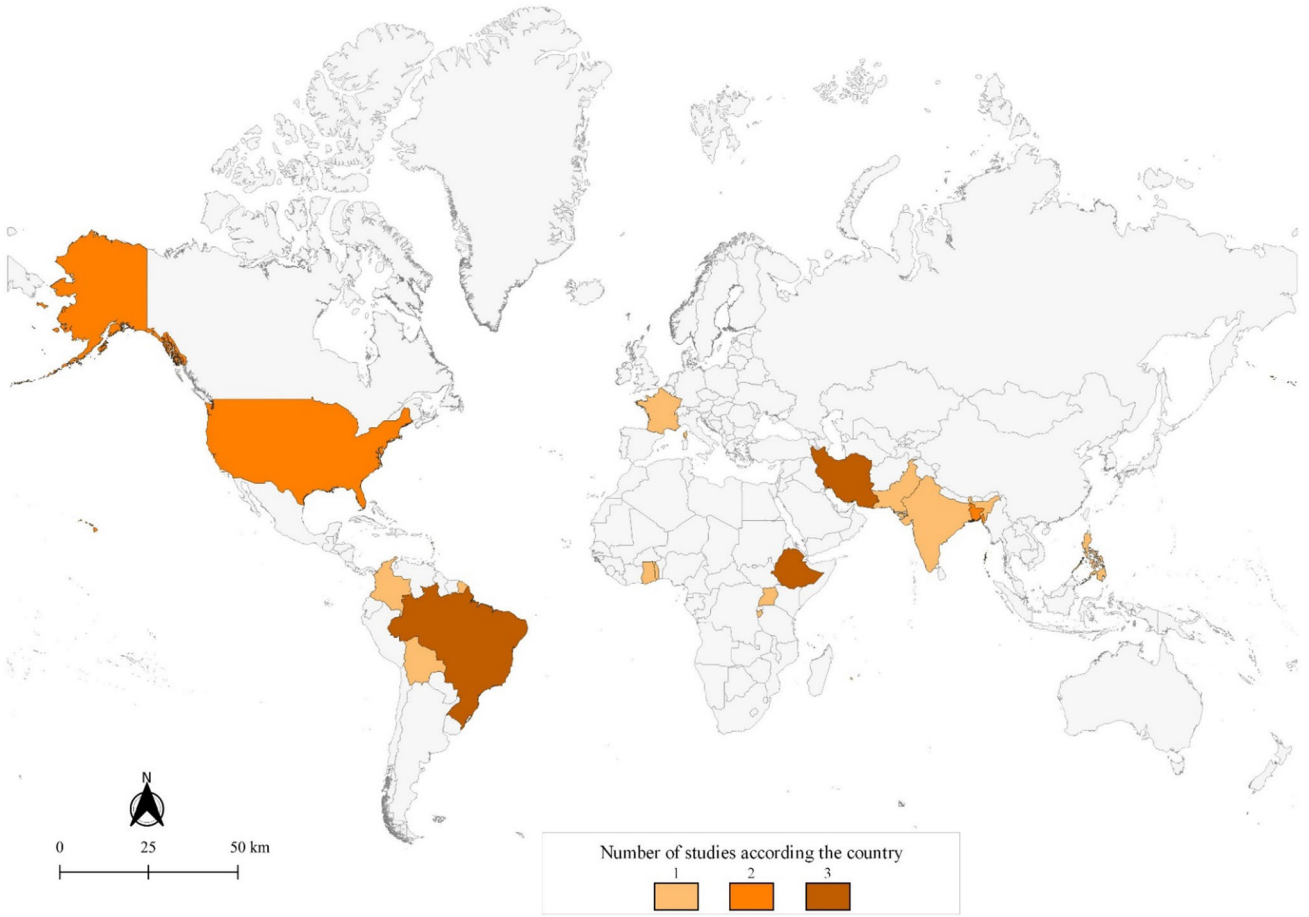

Fig. 3 Spatial distribution map of the analyzed studies on climate resilience in the family farming context, published between 2000 and 2021, according to the conducting country and the number of studies. The names, styles, and geographical limits expressed do not constitute any expression of opinion by the authors regarding the legal status of each country or the delimitation of its borders. *Source* Prepared by the authors using the QGIS software, 2022

Such directions involve early interventions of local climate actions implementation to incorporate climate adaptation technologies (Ali 2021; Mamun et al. 2021), develop profitable and just rural household production systems (Lindoso 2013), strengthen agroecology, organic farming, and local knowledge (Jacobi et al. 2014; Bulla and Steelman 2016; Guyot 2018; Heckelman et al. 2018), and improve the connection between science, policy planning, the local managers' actions, and the communities' needs (Bedeke et al. 2019). Growing summer crops and accessing non-farm employment opportunities can provide supplemental income, helping farmers survive under extreme weather conditions (Karimi et al. 2017; Bhalerao et al. 2021). Municipal agricultural agencies should encourage supplemental rainwater irrigation of crops, which increases yields, and reduces the risk of crop failure and flooding (Gebru et al. 2020).

We also noticed that families with young people involved in agricultural activities (Valliant et al. 2021), members of local organizations (Minani et al. 2013; Zakaria et al. 2020; Oyebola et al. 2021), or a broad social connection with friends, community, and family (Bulla and Steelman 2016) were more receptive to adopting productive practices adapted to the climate and productive diversification. However, socio-economic factors, such as education level, access to resources, updated information on agriculture and anticipatory disaster alerts, use of smartphones for agricultural purposes, degree of investment autonomy, training and extension workshops, agricultural insurance (Andrade 2013; Karimi et al. 2017; Bedeke et al. 2019; Gebru et al. 2020; Naqvi et al. 2020; Zakaria et al. 2020; Ahmed et al. 2021; Keshavarz and Moqadas 2021; Oyebola et al. 2021), and environmental beliefs influence how farmers deal with climate change (Andrade 2013; Keshavarz and Moqadas 2021). As a result, the importance of investing in the empowerment of rural families must be considered in the scientific, political, and social agendas because this action tends to directly influence the development of contextualized responses and strategies to overcome the producer's daily challenges, especially to reduce agricultural and livestock damage.

Table 2 List of reviewed studies that are referring guidelines orientation to public policies for rural climate resilience or climate risk management at the local level by focus measures

Focus measures	References
Reducing vulnerabilities of production systems and improving farmers' livelihoods	Lindoso (2013)
	Ahmed et al. (2021)
Support for the development of local associations	Minani et al. (2013)
Structural measures for climate-smart agriculture	Turbay et al. (2014)
Enabling credit and rural insurance	Guyot (2018)
	Zakaria et al. (2020)
	Ali (2021)
Rural extension, consultancy, technical support, and training for diversification of agricultural practices	Karimi et al. (2017)
	Asmare et al. (2019)
	Bedeke et al. (2019)
	Zarei et al. (2020)
	Oyebola et al. (2021)
Improvements of physical infrastructure such as rural roads	Gebru et al. (2020)
Improve human, social, and financial capital in family farming	Naqvi et al. (2020)
	Keshavarz and Moqadas (2021)
Technologies that maximize profits and ensure environmental protection	Bhalerao et al. (2021)

The main barriers affecting climate resilience in family farming were discussed and analyzed in the studies included in this review. These challenges are generally associated with policy incentives supporting family farming such as product certification, financial support, sustainable management, and climate knowledge and information, production outlets, price of agricultural inputs (Turbay et al. 2014; Ali 2021; Bhalerao et al. 2021). Further challenges affecting climate resilience include generalist actions, rural poverty, lack of know-how, deprivation or inadequate access to arable land, and the diminishing role of the state (Lindoso 2013; Minani et al. 2013; Heckelman et al. 2018; Bedeke et al. 2019; Zarei et al. 2020; Bhalerao et al. 2021; Keshavarz and Moqadas 2021), as well as the lack of access to agricultural tools, genetically improved species, and inappropriate use of inputs (Oyebola et al. 2021). In most studies regarding family farming, the most evident limiting factors include access to markets and human and financial capital (Andrade 2013; Minani et al. 2013; Turbay et al. 2014; Guyot 2018; Bedeke et al. 2019; Perrin et al. 2020; Ali 2021; Keshavarz and Moqadas 2021; Oyebola et al. 2021).

Increased pests, diseases propagation, weeds, soil erosion, reduced soil fertility, and water crisis (Gebru et al. 2020; Zakaria et al. 2020; Bhalerao et al. 2021; Mamun et al. 2021) floods (Ahmed et al. 2021; Oyebola et al. 2021) and temperature increase (Jacobi et al. 2014) comprise the main challenges of agronomic practices. Appropriate technologies and management practices optimize the use of natural resources (Lindoso 2013), and crop diversification in addition to reducing the impacts of climate change assists in increasing farm income, reducing workload, and availability of leisure time (Asmare et al. 2019).

On the other hand, temporary migration, and the sale of agricultural or non-agricultural labor are income supplementation strategies that strongly influence the ability to implement adaptive actions and generate opportunities for new agricultural learning on other farms and regions. High levels of agrobiodiversity and recording efficient on-farm agricultural practices should be considered to assist in improving climate resilience (Heckelman et al. 2018). This supports evidence that diverse pathways should be explored to generate robust adaptive actions to reduce climate shocks.

Climate change adaptation actions

Since climate resilience is fundamental in the current context and relates to the ability to adapt to climate risks in prone agricultural systems, we included adaptations described in the literature reviewed in our analysis.

They provide important elements in different contexts. For example, in the use of mixed cropping systems, changes in the variety type, improved seeds with earlier maturity or drought tolerance, planting date adjustments, row cropping systems, livestock crop integration (Zakaria et al. 2020; Ali 2021), and soil and water conservation and erosion control practices (Minani et al. 2013; Heckelman et al. 2018; Bedeke et al. 2019; Bhalerao et al. 2021). Reducing the cultivated area and avoiding second cropping can also help to improve adaptation to climate risks (Keshavarz and Moqadas 2021). Studies also have pointed

to installing or altering the irrigation system (Perrin et al. 2020; Zarei et al. 2020; Keshavarz and Moqadas 2021; Mamun et al. 2021), crop rotation, use of short-cycle varieties (Lindoso 2013; Ahmed et al. 2021), extending the harvesting period, cover cropping (Turbay et al. 2014), crop succession, crop protection with photovoltaic panels for solar energy generation (Bulla and Steelman 2016), circular vegetable beds (Andrade 2013), and planting in the leaky areas (Lindoso 2013). Furthermore, minimum and strip cropping systems, green manuring (Zakaria et al. 2020), polyculture, organic fertilization (Bulla and Steelman 2016; Asmare et al. 2019; Ali 2021; Valliant et al. 2021), mineral fertilization (Minani et al. 2013), fertilizer and pesticide amendments (Mamun et al. 2021), home manufacture of inputs such as seeds, pest and disease control methods, natural fertilizers, local seed banks (Heckelman et al. 2018), tree planting (Jacobi et al. 2014; Ahmed et al. 2021), and reclamation of degraded areas (Turbay et al. 2014; Guyot 2018) are documented.

Overall, in animal breeding, farmers have been increasing genetic diversity (Perrin et al. 2020), adopting new shelters (Bhalerao et al. 2021) and changes in the first breeding season (Oyebola et al. 2021). Livestock farming has been adopting several strategies, such as: rotated and post-harvest residue grazing, mixed herding, growing forage crops for feed supplementation, buying feed (Karimi et al. 2017), moving herds to outflow pastures, haying, silage (Lindoso 2013), reducing the number of animals, and changing feed ingredients (Keshavarz and Moqadas 2021). Another adaptation is the acquisition of new pastures to reduce the pressure on arable areas (Perrin et al. 2020). Furthermore, fish farmers have been applying bovine manure to ponds, using higher-quality species, and changing the harvest schedule (Bhalerao et al. 2021).

Rainwater collection (Ahmed et al. 2021) on rural roads (Gebru et al. 2020), in situ (Lindoso 2013) or in cisterns (Andrade 2013; Guyot 2018) is documented. Other families have built water reservoirs (Perrin et al. 2020), deepened wells, or bought extra water (Lindoso 2013; Keshavarz and Moqadas 2021).

The data suggest that climate change forces farmers to migrate temporarily in search of non-agricultural income and this is a relevant part of rural household socioeconomic strategy (Karimi et al. 2017; Keshavarz and Moqadas 2021; Mamun et al. 2021). Such evidence calls for alternative visions of strengthening sustainable rural communities with important combinations and pathways to climate resilience.

Sustainable family farming proves resilient to climate but vulnerable—metatexts

Increasing climate resilience in family farming incorporates a major challenge that is related to the complexity of the transformations needed to ensure food production with less impact on ecosystems and climate. Such advances, on the other hand, need to be robust, integrated into interdisciplinary, intersectoral, and systemic frameworks, and consistent with sustainable rural development. Climate change is a common challenge for agriculture in many parts of the globe, at different levels of impact and sectors affected (Andrade 2013; Lindoso 2013; Minani et al. 2013; Jacobi et al. 2014; Turbay et al. 2014; Bulla and Steelman 2016; Karimi et al. 2017; Guyot 2018; Heckelman et al. 2018; Asmare et al. 2019; Bedeke et al. 2019; Gebru et al. 2020; Naqvi et al. 2020; Perrin et al. 2020; Zakaria et al. 2020; Zarei et al. 2020; Ahmed et al. 2021; Ali 2021; Bhalerao et al. 2021; Keshavarz and Moqadas 2021; Mamun et al. 2021; Oyebola et al. 2021; Valliant et al. 2021).

Interpretation of the data submitted to DTA made it possible to identify components to support climate resilience in rural household settings. Based on these codes' categorization, this study identified 4 final categories, organized by the fusion of elements present in the 23 studies analyzed. The synthesis of DTA can be found in the Supplementary Information (Fig. S1).

Resilient family farming consists of the interplay of socioeconomic, political, and environmental factors that can be further worked out and provide relevant contributions to the success of sustainable rural communities and thus also to climate-resilient territorial development (Fig. 4). We summarize these four dimensions in topics:

(a) Environmental education and communication: From a formative perspective, climate resilience is influenced by the quality of information passed on to peers and the internalization and representation of contexts. In other words, it is directly related to farmers' knowledge. Thus, providing meaningful educational opportunities in the various typologies of environmental education, valuing local environmental knowledge and dialogue of knowledge, reflects the plurality and the construction of innovative, and transdisciplinary education, able to show that climate change is an emergency. Strengthening systemic thinking and criticality in dynamic communicative processes with clear, focused, comprehensive, and liberating languages is fundamental to suppressing the limiting gaps in the resilience potential of rural communities. In this category, we see critical points that deserve attention. For example, the need to increase rural households' knowledge about climate change, access to information (Keshavarz and Moqadas 2021) and use pedagogical tools in educational programs and projects to build climate-resilient agricultural systems and communities (Perrin et al. 2020).

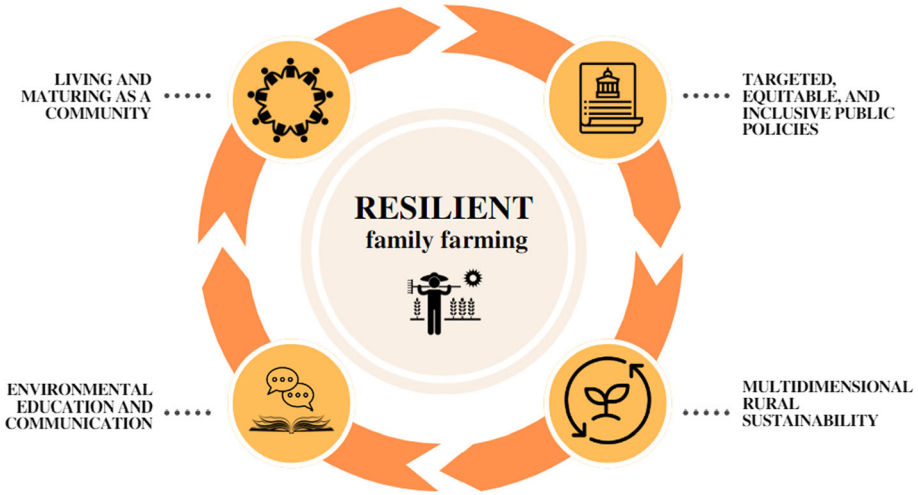

Fig. 4 Conceptual dimensions of final emerging categories that contribute and constitute their transformative capacity in the context of family farmers' resilience to climate change to promote sustainable rural development are identified from a synthesis of the reviewed literature. *Source* Survey data, 2022

(b) Living and maturing as a community: In this interpretation, climate resilience requires more than techniques, strategies, or technological approaches. It requires, above all, that human beings have more respect for the planet earth, and empathy for others. The way relationships are built and how rural families specifically organize their practices in the rural work system relate to discovering the real meaning of living together in a community, whether in the family sphere, dividing tasks, or in the other existing relationships. Responsible and careful management of the ecosystem and resilience to climate change needs to consider the collective maturing of the understanding that there is one planetary community. By way of example, this category expresses the need for joint resilience actions such as collective seed banks, enhancing trust and support relationships between farmers and community, which can contribute to the exchange of inputs or labor (e.g., after extreme weather events) or to the livelihood of farmers who need to market their products on a short scale (Bulla and Steelman 2016). Such connections increase the capacity for organization and cooperation, as well as the sharing of successful resilient experiences (Bedeke et al. 2019).

(c) Multidimensional rural sustainability: The conjuncture of climate resilience in family farming mainly portrays a different notion of production than the one we are commonly used to. It demands the adoption of environmentally adequate productive practices, in defense of a healthy and sustainable food system. Furthermore, it advocates the need to disseminate diversified organic agriculture and a range of ecosystem services, such as soil protection, biological control use, water efficiency, and rural tourism. Multidimensional rural sustainability needs to be understood beyond its conceptual framework. It is robust because it contemplates new dimensions and values constantly re-signified in family farming systems. Supporting good agricultural practices and sustainable production, ensuring productivity and quality are avenues to be contemplated, as are, for example, stimulating agroforestry production systems (Ali 2021) using rainwater in irrigation to ensure water efficiency (Gebru et al. 2020), increasing the diversity of methods for organic production, and stimulating agro-environmental sustainability (Heckelman et al. 2018) with long-term interventions for contextualized rural development.

(d) Targeted, equitable, and inclusive public policies: Sustainable climate resilience must be linked to public policies in local, integrated, context-oriented rural interventions that provide effective participation of the community, youth, women, and other vulnerable groups in building specific programs that meet their needs. These experiences need to be associated with the adoption of accessible and sustainable practices and technologies, simultaneously strengthening climate-resilient production and commercialization networks in a territorial development package. For example, studies have called for attention to incorporating farmers into public policy-making discussions (Ahmed et al. 2021), proposals that consider heterogeneity in production systems (Asmare et al. 2019), and the urgency for continuous stakeholder interaction, tensing the enhancement of policy actions

across multiple segments that can aid climate resilience (Zarei et al. 2020).

Overall, these indications of engagement should be structured to ensure a different relationship with the land, promoting a fair, inclusive food system (Bulla and Steelman 2016) capable of combining productivity, resilience, and sustainability in agriculture (Zakaria et al. 2020; Ahmed et al. 2021). It is understood that the main agglutinating argument of the four findings is that family farming climate resilience in the Sustainable Rural Development context is a dialogical, collective, political, formative, and ever-changing process that requires local robustness. This includes structuring specific action plans and interventions (Jacobi et al. 2014; Zarei et al. 2020).

DISCUSSION

Climate resilience recognized as a major challenge of the century has emerged as correlated with viable alternatives within productive systems and opportunities for improvement, in terms of adaptation strategies to assist household livelihoods. Particularly, the challenge is to understand the integrated local, and regional dynamics and execute sound actions, capable of integrating biases, to address the current challenges imposed by climate and environmental change (Thompson-Hall et al. 2016; Singh et al. 2021).

Thus, given the intensification of the debates on climate resilience in recent years, other previous studies have sought to link family farming to ensure food sovereignty. For example, Ploeg (2014) describes that the pluriactivity of livelihoods and the extensive relationship of family farmers with local nature are elements that can collaborate with the conservation of ecosystems and local biodiversity, directly reflecting the movement to deal with climate change.

However, these studies were not focused on understanding the multiple dimensions of climate resilience in family farming from the sustainable rural development perspective. In our research, we conducted a scoping review of the global literature, using a strict search and selection framework to shed light on the microdynamics that embodies this topic. Generally speaking, we observe that climate change resilience is mostly stimulated by the diversity of local cultures and biodiversity. Similar to the conceptions of Altieri and Nicholls (2021) and Joshi et al. (2021), monoculture cropping, and intensive use of chemical inputs are central element disabling resilience in agricultural systems, especially to biological and natural disasters.

Our results have shown that, in general, adaptation actions are expressed as connected solutions based on the experiences of communities, available technologies, modes of management, and cultivation. This is because farmers in different contexts have diverse experiences, which influence climate risk perception and adaptation behaviors. Undoubtedly, immediately facilitating access to agricultural inputs, incrementing technologies and equipment, and encouraging alternative farming and livestock practices are important steps to support farmers' resilience (Mensah et al. 2021; Abbass et al. 2022; Tiet et al. 2022). This result suggests that farmers tend to seek technical solutions and management strategies based on their needs, impacts, and available resources.

In light of different climate scenarios, there is a need to focus on resilient and combined rural practices for sustainable improvement of production systems. Baseline efforts from appropriate agronomic packages are critical to maintaining ecosystem balance and adaptation to climate change (Singh et al. 2022).

Our results show that according to the literature, four main elements offer the main directions that need to be considered for agricultural systems to become more climate-resilient. A Sustainable Rural Development perspective highlights the relevance of improving the social, political, and economic structures inherent to sustainability for reducing inequalities and poverty (Smith et al. 2017; Aryal et al. 2020). These results also confirm the findings of Gach (2019) and Mensah et al. (2021), who indicate that amplifying the voices of subjects in policy plans and breaking down the barriers of access that limit family farming is fundamentally a dimension of climate justice, which can collaborate with capacity building to face challenges with greater confidence.

However, this study has identified that the biggest challenges to rural community resilience are the availability of financial resources, information, knowledge, and the lack of effective policy incentives, access to markets, and credit services. This result is consistent with existing literature that the quality of the local framework and government involvement is critical for risk reduction and adaptation to climate change (Abbass et al. 2022; Dhanya et al. 2022; Tiet et al. 2022). This suggests that additional efforts and specific policy strategies on these issues are essential.

From this perspective, Milhorance et al. (2021) observed that, although the formulation of climate resilience policy strategies combines the articulation of different sectors and the pursuit of territorial development, supported priorities and divergences have weakened the incorporation of efforts. Another impasse concerns the creation of comprehensive initiatives that do not involve governments, departments, and municipal associations and disregard the advance of climate change. Therefore, it becomes relevant to align climate agendas with the actors involved, creating

spaces for interaction, production, and communication on climate resilience.

This study identified that the provision of quality education is associated with improved adaptive capacities. These findings extend those found by Pérez et al. (2020), Tagliapietra et al. (2021), and Dhanya et al. (2022), confirming that education is one of the critical points in decision making in the face of climate change and offers significant contributions to sustainable rural development.

Therefore, climate resilience policies and actions must be accompanied by educational actions, starting with rural extension and technical assistance services, with objectives that can expand the acquisition of knowledge, experiences, and skills to face the challenges of sustainability (Matos Carlos et al. 2019; Ardoin et al. 2022).

We find that farmers' lack of involvement in the local class institutions and associations also limits their prospects for improving social networks, knowledge, and adaptation capacity. Within this context, strengthening the participation of farmers in social groups and organizations, from networks of local actors is fundamental for the formulation of transformative actions, because this involvement increases access to financial support and the collective mobilization of communities to respond to obstacles (Milhomens et al. 2021; Silici et al. 2021; Carmen et al. 2022) such as extreme climate events.

CONCLUSION

This review summarized the theoretical dynamics of the scientific discussions regarding climate resilience in family farming and its relation to the promotion of sustainable rural development. Although the subject has been little associated directly with the term sustainable rural development, research resilient and sustainable small-scale agriculture are highlighted and involve a variety of methods, production activities, and regions.

Our study demonstrates that a strong emphasis on the dimensions of meaningful communication between extensionists, local social organizations, scientists, non-governmental organizations, and other actors should be considered. According to the review of publications, co-produced public policies and united communities supported by sustainable agricultural practices, contribute to increasing resilience. The findings reiterate, therefore, that resilient family farming will have to be achieved through everyday improvements in territorial configurations from a locally inclusive, equitable, and participatory perspective.

Using different adaptation strategies, in combination and contextualized, to overcome climate challenges is generally efficient, can reduce impacts, and provide co-benefits and synergies. However, the adaptation arrangements should integrate new technologies, innovations, and mechanisms for the sector, based on long-term action planning.

The obtained results confirmed that climate change makes agrifood systems vulnerable. The strong articulation between government priorities and local communities can contribute to climate resilience in the context of sustainable rural development and promote better living conditions for farming families.

The scenarios and implications of climate change with distinct specifics of agriculture and new approaches are important. Social and political efforts to reduce climate risks in family farming could focus more on action plans and projects for rural areas, combined with implementing actions to enhance local agriculture. These include adding value to family production, strengthening marketing channels, and offering services of training, to support and increase their recovery chances in climate crises.

This study is one of the first scoping reviews to investigate the climate resilience relationship in family farming based on sustainable based matrices, in different agricultural practices and regions of the world.

However, we have identified some limitations that are worth noting. First, this study used only a qualitative approach, and thus quantifiable variables cannot be fully identified. Second, even though our study does not focus on health, the findings indicate that the reduced resilience to climate change could affect planetary socioenvironmental vulnerability. Therefore, we recommend that future studies should include a quality-quantitative investigation to verify the impacts of climate change on food and hydric security.

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Declarations

Conflict of interest The authors have no conflict of interest to declare that might have influenced the work reported in this paper.

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