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A systematic review of smallholder farmers' climate change adaptation and enabling conditions for knowledge integration in Sub-Saharan African (SSA) drylands

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ABSTRACT

Adaptation is important in drylands to enhance the climate change resilience of inhabitants who depend on the environment for their livelihoods. Dryland farmers in sub-Saharan Africa (SSA) have shown the ability to adapt to a changing climate in the past. However, anthropogenic climate change is leading to a more rapidly changing environment that will surpass farmers' previous experiences and capacity, making it harder for them to adapt. This systematic review of empirical studies of farmers' adaptation in SSA drylands from 1990 to 2021 shows that farmers have used an array of strategies to respond to changes in their environment and climate based on local and scientific knowledge. Although both types of knowledge have their effectiveness, they also have gaps and challenges. Thus, there is growing evidence that farmers are integrating the two knowledge types to help them close the gaps in their knowledge and increase the effectiveness of adaptation strategies implemented. The review further reveals the existence of various enabling conditions for knowledge integration such as stakeholder engagement and buy-in, continuous learning and improvements, access to extension, and government, scientific and policy support. Other enabling conditions are the role of different institutions, market access, identification of existing practices, equitable access to natural resources, enforceable property rights and consistency of practices.

1. Introduction

Drylands are areas where the annual precipitation (P) and the potential evapotranspiration (PET) ratio (P/PET) are between 0.05 and 0.65 (UNCCD, 2017). They constitute the earth's largest biome, covering about 41.3% of the land surface (KIPKEMOI et al., 2021; UNITED NATIONS, 2020). Drylands directly provide important ecosystem services to about 2.1 billion people globally (ibid), of which more than 80% are in Low- and Middle-Income Countries (KOOHAFKAN and STEWART, 2008). Drylands provide grasslands, forests, agricultural lands, and urban areas for habitation (KOOHAFKAN and STEWART, 2008; UNITED NATIONS, 2020). For example,

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globally, drylands support some 44% of cultivated systems (mostly in the dry sub-humid zones), and 50% of the livestock population (mostly in the arid zones) (United Nations, 2020). However, drylands are characterised by high rainfall variability, prolonged drought periods, and water scarcity problems, which drastically limit ecosystem services provision (GUODAAR et al., 2021; KOOHAFKAN and STEWART, 2008).

Water scarcity problems are expected to worsen under the current climate change scenarios, both because of increasing rainfall variability, decreasing rainfall amounts and the depletion of groundwater resources and to be exacerbated by human activities, such as poor management and overuse of water (OGBAGA et al., 2020; UNITED NATIONS, 2020). In sub-Saharan African (SSA) drylands, rainfall scarcity affects inhabitants' livelihoods due to their reliance on rainfed agriculture for their subsistence, making them particularly vulnerable (WARD, 2016). The increasing water scarcity in drylands limits the two key functions of land-nutrient cycling and primary production (SAFRIEL and ADEEL, 2005), and can eventually lead to desertification (D'ODORICO et al., 2013; ZENG et al., 2021). As a result, the need to focus on adaptation has gained traction in different knowledge and policy domains over the last four decades. The Intergovernmental Panel on Climate Change (IPCC) defines adaptation to climate change as the change in the socio-ecological systems in response to perceived or real climatic stimuli or impacts, to lessen climate change effects (IPCC, 2001b).

Most studies on climate change adaptation in drylands have either focused on Asia (FANG et al., 2019; GANG et al., 2019; WU et al., 2019; YAN et al., 2019), on social issues such as justice and equality (OWEN, 2020); on farmers' local knowledge (MORTIMORE, 2003; MORTIMORE and ADAMS, 2001) or scientifically based knowledge alone (ADGER et al., 2011; BOKO et al., 2007). Few studies have specifically focussed on SSA drylands (THORNTON et al., 2018), or the enabling conditions for integrating farmers' local knowledge about the causes of, and responses to climate change with scientific knowledge systems (e.g., DAVIES, 2017; HIWASAKI et al., 2014; OLAZABAL et al., 2018; REED et al., 2007; VOHLAND and BARRY, 2009). Further, many scholars do not regard farmers' local knowledge as scientifically valid in its own right, but rather as a tool for documentation (SALITE, 2019), even though farmers' knowledge has been developed through experimentation, adaptation, and co-evolution (TENGÖ et al., 2014), and culturally transmitted over generations (SALITE, 2019).

Local knowledge comprises cultural traditions, values, and belief systems of the local people, transmitted, adapted, and refined over generations (AGRAWAL, 1995; DEI, 1994; IPBES, n.d, ORLOVE et al., 2010). It arises from the local people's dependence on their surrounding environment, their repeated observations of nature, and interpreting the changes to make their livelihoods-related decisions (ibid). Local knowledge is considered essential for the survival of most rural people as it has provided them with the ability to understand their surrounding environment, to recognise changes within it and to develop diverse strategies to deal with the changes, secure their livelihoods and survive (ADGER et al., 2007; DEI, 1994; LOUIS, 2007). However, there is no consensus on what constitutes farmers' local knowledge, its merits, value and how it is constructed (AUDEFROY and SÁNCHEZ, 2017; BENTLEY and THIELE, 1999 DEI, 1994). This in part is because local knowledge has not been fully considered and explored in climate change adaptation (AJANI et al., 2013; FABIYI and OLOUKOI, 2013; MERTZ et al., 2009; OUDWATER and MARTIN, 2003).

Although farmers' local knowledge can be a valid and useful tool for adaptation (TENGÖ et al., 2014), scientific knowledge continues to represent the benchmark of all knowledge types (KLENK et al., 2017). Scientific knowledge refers to the outcome of scientific activity that produces models, theories and laws based on observations and experimental data (ERDURAN et al., 2019). The assumption within the domain of the 'sociology of scientific knowledge' has been that knowledge production and validation occur within scientific research sites or laboratories (MILLER, 2008). However, scientific knowledge is generally not adopted by many farmers in developing countries (SALITE, 2019).

Farmers' local knowledge can complement scientific knowledge through integration (SALITE, 2019; TENGÖ et al., 2014). Knowledge integration can support an enhanced social learning process by providing a diverse and enriched picture of climate change issues (TENGÖ et al., 2014), and a range of perspectives on potential adaptation options that support resilience (REED et al., 2007). Integrating farmers' and scientific knowledge has been shown to produce better results than using just one knowledge source (GUODAAR et al., 2021; MERCER et al., 2010; REED et al., 2007). Knowledge integration supports effective communication of science and technological benefits to communities, with adaptation strategies embedded in bottom-up approaches (AMARU and CHHETRI, 2013; GUODAAR et al., 2021). Such approaches strengthen the success of the adaptation strategies and increase farmers' adaptive capacity to climate change (SALITE, 2019). However, the success of this integration requires that researchers and practitioners understand the context-specific nature of dryland farmers' use and management practices of their agricultural lands (REED et al., 2007; TOULMIN, 2009). This will further aid the transmission of scientific knowledge in a meaningful and relevant way to support farmers' decision-making and empower them to take the expected actions (SALITE, 2019).

For example, studies from Sahelian drylands (e.g., MORTIMORE and ADAMS, 2001; MORTIMORE, 2005a) indicate that despite the instability of the system, it has been resilient as farmers engaged in different farming activities due to their accumulated experiences of farming, keeping the best of their seed landraces for the next season after harvest (MORTIMORE, 2003; NELIMOR et al., 2019). However, such seed management practice has been declining, especially in the past two decades, as there has been a 15% increase in dryland farmers' adoption of improved crop varieties that are drought-tolerant and high-yielding (WALKER et al., 2016).

Although in the last three decades, scientific knowledge has provided insightful contributions to address drylands' problems such as land degradation (CORELL, 1999), this knowledge also has its limitations. Evidence from national and international agencies shows that scientific knowledge cannot always accurately diagnose problems or provide solutions to land degradation (REED et al., 2007). This is due in part to the top-down and prescriptive nature of scientific knowledge that does not consider the multifaceted nature of climate and environmental change (GARCIA and FEARNLEY, 2012). This approach excludes the participation of the affected communities, which can lead to bias (REED et al., 2007). With the rise of participatory research in the 1970s and 1980s, new studies emphasized the benefits of farmers' and pastoralists' local knowledge, and the benefits of stakeholder engagement in environmental management (REED et al., 2007; 2018). Previous approaches to participatory research have been criticised for reinforcing existing power structures and further marginalising the less privileged in communities (KOTHARI, 2001). A successful participatory approach for knowledge integration requires an adequate representation of stakeholders, and a well-structured facilitation process to balance power relations (DE VENTE et al., 2016; REED et al., 2006, REED et al., 2018; TARCHIANI et al., 2020; VINCENT et al., 2018).

This study aims to review the literature from 1990 to 2021 on SSA drylands farmers' coping and adaptation strategies to respond to the increase in the frequency of drought and decline in rainfall, exacerbated by climate change (IPCC et al., 2001a; VOGEL and O'BRIEN, 2003). The study also aims to provide a distinct contribution to the ongoing conceptual debate and practical pursuit of adaptation strategies of SSA dryland inhabitants through exploring the enabling conditions for knowledge integration. There is no specific definition of enabling conditions for knowledge integration.

To address the aim of the paper, we intend to answer two research questions:

i. What are the approaches and strategies used by small-scale farmers to cope and adapt to climate change?
ii. How is local and scientific knowledge integrated to promote coping and adaptation to climate change?

To answer these questions, we adopted a systematic review of as many relevant research papers on SSA drylands' adaptation based on established criteria appropriate for the study as we could find. In sections 3 and 4, the results are presented, followed by a discussion of the theoretical and practical implications, and we conclude in section 5.

2. Methodology

2.1. Data acquisition

In the initial search of papers for the systematic review, we found 3065 references to papers that explore the knowledge types and sources for adaptation implemented by smallholder farmers in SSA drylands and the enabling conditions for knowledge integration. The systematic approach aimed to ensure that the review was reproducible and a dependable appraisal of the existing body of knowledge in this field (GUITART et al., 2012). The methodology was adapted from earlier studies (e.g., GENTIN, 2011; GUITART et al., 2012; PETTICREW, 2001; STEVEN et al., 2011) and comprises systematic identification, selection, and categorisation of papers (Table 1).

We used Elsevier Scopus, Web of Science and Google Scholar as the key literature sources because they are considered reputable databases and contain peer-reviewed papers. Only articles in English were included in the review due to the proficiency of the researchers. We used keywords ('Dryland resilience', 'Resilience drylands', and 'Adaptation drylands'), abstracts, and titles to select the most important papers for inclusion (Table 1). We applied inclusion and exclusion protocols for the selection, in line with the objectives of our review (Table 2). Studies reviewed included those related to crop production and livestock management such as rangeland and pastoral systems. We recorded the following information from each paper included in this review, building on GUITART et al. (2012) criteria: author (s); journal name; year of publication; location of adaptation study; paper focus; methodology of the study; and type of adaptation and coping strategies employed (Table 2).

We checked the reference section of the reviewed papers in search of any relevant papers that may have been left out by the search string and criteria used for inclusion and exclusion (Table 2). After screening the papers, titles and abstracts, we excluded a total of 2899 papers from the review for not falling within the scope of this study (Table 2). We selected and read 166 papers to determine eligibility, and only 58 articles were appropriate for the review, according to the selection criteria and after removing duplicates. The complete list of adaptation and coping strategies identified in the literature can be found in Appendices B.1 and B.2.

2.2. Data analysis

We summarised the key variables of interest (location of study, type and source of knowledge for coping and adaptation to climate change) for the 58 papers included in the systematic review. We identified papers that utilised autonomous strategies and messages that were either local or scientific knowledge for adaptation. Content analysis of the selected papers was carried out to explain the findings from the study and elicit the enabling conditions for knowledge integration. We critically appraised the study approaches and methodologies, sources of knowledge for adaptation, location/country of the papers included.

Table 1
Paper search criteria from Elsevier Scopus and Web of Science.

Keywords	No. of papers-Web of Science (1990–2021)	No. of papers-Elsevier Scopus (1990–2021)	Other sources (Google scholar)	Total papers
"Dryland resilience"	141	726	159	**999**
"Resilience drylands"	84	–	–	**84**
"Adaptation drylands"	108	1847	–	**1955**
Total papers	**333**	**2573**	**159**	**3065**

Table 2
Inclusion and exclusion criteria for articles in the review.

Criteria	Included	Excluded	Justification for criteria application
Publication date	1990 to 2021.	Before 1990.	Used papers from carefully chosen databases to give a historical perspective on adaptation and resilience in SSA drylands.
Publication language	Articles in English language	Papers not written in English	To increase readability and due to researchers' knowledge of English language only.
Publication theme	Articles on resilience and adaptation to climate change.	Papers not based on adaptation and resilience.	To remain within the scope of the systematic review.
Availability of article	Fully available open access papers	Complete paper not available	Due to not being open access, thereby requiring purchasing.
Type of article	Peer reviewed research journal article	Conference abstracts, unavailable book chapters, review papers.	Interested in available peer reviewed empirical or original research.
Country or location of study	SSA papers.	Non-SSA articles.	To maintain scope of the review.

3. Results

3.1. Characteristics of existing literature on SSA drylands' coping and adaptation

The review showed that farmers face different challenges in their farming activities such as changes in climate (drought, flood, and excessive heat) often attributed to climate change that require coping or adaptation. Farmers have used different sources of knowledge to overcome the challenges. The description of the sources of knowledge covered in the review is presented in the subsequent sections and in the appendix (Appendix A). Most studies were based on either qualitative or quantitative methods and a few studies used mixed methods. The quantitative study design helps in understanding the frequency and percentage of occurrence of practices while the qualitative helps in proffering explanations of the emerging themes.

In terms of the geographic scope covered, the reviewed papers showed diverse drylands adaptation strategies in SSA, mostly from farmers in Eastern Africa (43.10%), followed by Western (36.21%) and Southern (18.97%) Africa. Each paper focuses on one specific country, and only one of the papers had multiple countries which include Kenya, Ethiopia, Tanzania, and Uganda (Eastern Africa), Ghana, Burkina Faso, Mali, Senegal, Niger (Western Africa) and it is presented as a 'multi-country' paper (see Fig. 1).

Papers analysed in this review are from journals in various disciplines related to environment and climate. *Global Environmental Change* is the journal with the highest number of papers reviewed (5 papers out of the 58 papers reviewed) followed by the *Journal of Arid Environments* and *Regional Environmental Change* with 4 papers each. The remaining journals had one or two papers each (Appendix D).

3.2. Source of adaptation and coping strategies reported in the reviewed studies

The systematic review showed the existence of three knowledge sources for coping and adaptation, namely local, scientific, and integrated knowledge. Some farmers recur to the use of adaptation strategies based on scientific knowledge such as irrigation, adoption of drought-tolerant crop varieties, and agroforestry, while other farmers integrate strategies from both local and scientific knowledge

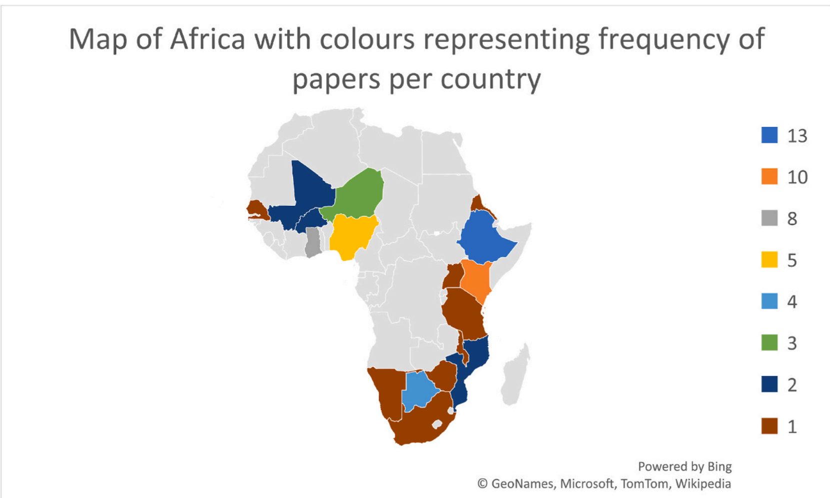

Fig. 1. Number of papers included in this review based on country of studies ($n = 58$).

sources. This is further discussed below.

3.2.1. Farmers' coping and adaptation strategies based on local knowledge

Thirty papers included in the review identify farmers' local knowledge as the only source of adaptation or coping strategies as no external support from extension or research was reported in these studies (Appendix A). Adaptation strategies based on local farmers' knowledge include mulching (SPERANZA, 2013), dry season farming using irrigation, and mixed cropping (AHMED et al., 2016; BERHE et al., 2017; NDHELEVE et al., 2017; SPERANZA, 2013; VILLAMOR and BADMOS, 2016). Coping strategies include alternative income generation through small businesses such as the sale of firewood and charcoal (EGERU, 2016; TESFAMARIAM and HURLBERT, 2017), prostitution (MOSBERG and ERIKSEN, 2015), and bush meat hunting (MOSBERG and ERIKSEN, 2015). Other strategies include seed storage, diversification of farming systems and livestock, selling of assets, migration and remittances, collection of wild fruits (ERIKSEN and SILVA, 2009), borrowing money (ERIKSEN and SILVA, 2009; MOSBERG and ERIKSEN, 2015), fishing (ERIKSEN and SILVA, 2009) and forest clearing (MOSBERG and ERIKSEN, 2015). For example, the Maasai in East African drylands hitherto managed climate trends through adapting their normal seasonal patterns of farming (LEAL et al., 2017). However, other farmers, mainly the poor and women farmers, have been shown to become more vulnerable with the use of their local knowledge alone amidst harsh environmental, climate and economic conditions (DIXON et al., 2014). This was also reported in Kenya and Tanzania by LEAL et al. (2017) and in the Kano Close Settle Zone (KCSZ) in North-Western Nigeria by MORTIMORE (2005b).

Table 3
Categories of adaptation [A]/coping [C] practices' frequency based on IPCC et al. (2014b) and OWEN (2020).

Structural and physical adaptation [A]/coping [C] practices (70)			
Engineered/built environment (18) • Building water-harvesting techniques at home and in field (9) **[A]** • Land levelling (3) **[A]** • Reduced run-off and erosion (2) **[A]** • Investment in transport (1) **[C]** • Construction of drainage & ditches (1) **[A]** • Fencing (1) **[A]** • Sand dams (1) **[A]**	**Technological (33)** • Use of drought tolerant and early maturing crop varieties (20) **[A]** • Irrigation provisioning (9) **[A]** • Purchased pesticides/herbicides (2) **[A]** • Pest resistant varieties (1)**[A]** • Mechanisation (1) **[A]**	**Ecosystem-based (18)** • Tree planting (10) **[A]** • Implementing water and soil conservation techniques (8) **[A]**	**Services (1)** • Use of available food (1) **[C]**
Institutional adaptation/coping practices (29)			
Economic (13) • Food for work (2) **[C]** • Improved access to water (2) **[A]** • Cash/vouchers for seeds and others (1) **[C]** • Financial and technical support (3) **[C]** • Loan during drought (1) **[C]** • Reliance on humanitarian aid (4) **[C]**	**Laws and regulations (0)**	**National policies and programs (16)** • Livelihood outside agriculture (12) **[A]** • Government support (3) **[C]** • Biodiversity management (1) **[A]**	
Social adaptation/coping practices (126)			
Educational (3) • Investing in education (1) **[A]** • Community sensitisation (1) **[A]** • Use demonstration farms (1) **[A]**	**Information (0)**	**Behavioural (123)** • Improved crop management (15) **[A]** • Migration/remittances (17) **[C]** • Sell assets (livestock and land) (13) **[C]** • Improved livestock management (14) **[C]** • Sell firewood and charcoal (11) **[C]** • Livestock movement at drought onset (12) **[C]** • Borrowed money (7) **[C]** • Support from family and neighbours (3) **[C]** • Brewing local alcohol (3) **[C]** • Altering the time of planting (3) **[A]** • Switching to climate sensitive crops (2) **[A]** • Mixed cropping (2) **[A]** • Early planting (2) **[A]** • New waged/casual employment (2) **[C]** • Alternative energy use (2) **[A]** • Prostitution (1) **[C]** • Theft (1) **[C]** • Bush meat hunting (1) **[C]** • Forest uses (2) **[C]** • Fishing (1) **[C]** • Diversifying farming systems (1) **[A]** • Reciprocity (1) **[C]** • Accumulation of financial & physical assets (1)**[C]** • Sale of labour (4) **[C]** • Flexibility (1) **[C]**	

Community elders' local knowledge was found to be useful in identifying the most palatable plant for livestock grazing in Ethiopia (LIAO et al., 2016). In the absence of early warning systems communicated through television and the public radio services (BELLE et al., 2017), local knowledge is used to forecast climate related changes such as timings of pest infestation, changes in animal's behaviour (SALITE and POSKITT, 2019). This is an example that buttresses the assertion that adaptation strategies to environmental change based on local knowledge are sufficient to cope with or adapt to prevent potential disastrous consequences of carrying on with normal farming patterns (LIAO et al., 2016). Conversely, LEAL et al. (2017) suggest that strategies based on local knowledge alone are no longer viable due to the impact of increased human and livestock population and increased frequency of minimum and maximum temperature fluctuation.

3.2.2. Strategies based on scientific knowledge

Only seven of the fifty-eight papers reviewed reported scientific knowledge alone promoted by extension services as the source of coping or adaptation strategies (appendix A). The strategies include the use of sand dams (RYAN and ELSNER, 2016), drought-tolerant and early maturing crop varieties, altering planting time, implementing water and soil conservation techniques and agroforestry (ARITI et al., 2015; SNOREK et al., 2014; TAMBO, 2016). Other strategies include switching to mixed cropping, and construction of drainage ditches. The use of scientific knowledge alone has been criticised in adaptation studies due to the top-down and one-size-fits-all approach and non-participatory nature, leading to low or no adoption of adaptation strategies (JELLASON et al., 2020), hence the need for integration of both knowledge epistemes (MORTIMORE, 2005a). In the next section, we explore how knowledge integration has been carried out by farmers, according to the literature reviewed.

3.2.3. Strategies based on integrated knowledge

For the integrated knowledge, some farmers reportedly received intense climate-related disaster (e.g., droughts, floods, and heatwaves) risk management messages from different sources such as the public radio services, diviners, humanitarian agencies, community meetings and the military (EGERU, 2016). Twenty-one of the reviewed papers reported the integration of local and scientific knowledge sources for coping and adaptation (e.g., BUNCLARK et al., 2018; EGERU, 2016; REED et al., 2007; SALLU et al., 2010; TOTIN et al., 2018; TREYDTE et al., 2017; VILLAMOR and BADMOS, 2016). The adaptation and coping strategies reported in the included studies were diverse (see summary in appendices B.1 and B.2), reflecting categories such as structural, physical, institutional, and social adaptation strategies important for socio-ecological systems' resilience promotion. These categories were used as a framework to analyse and group the adaptation and coping strategies and are based on OWEN (2020) and IPCC (2014) frameworks (Table 3).

3.3. Enabling conditions for knowledge integration

Our analysis indicates that all twenty-one studies that reported knowledge integration (Appendices A and C) implicitly suggested that understanding the enabling conditions for knowledge integration is key to successful implementation of coping and adaptation strategies. Six of the papers indicate stakeholder engagement and buy-in as the most significant enabling conditions, buttressing the importance of participatory approaches for successful knowledge integration. Different stakeholders operate at various levels, have diverse knowledge, values, and interests which are important for climate change adaptation decision-making (TOTIN et al., 2018). Other factors include continuous learning and improvements by farmers (mentioned in five papers), access to science and extension support, government policy support to farmers, and the role of different institutions, each mentioned in three papers. Other enabling conditions appeared in only one paper each (see Fig. 2).

Access to scientific, extension services, government, and policy support also proved to be important enabling conditions for

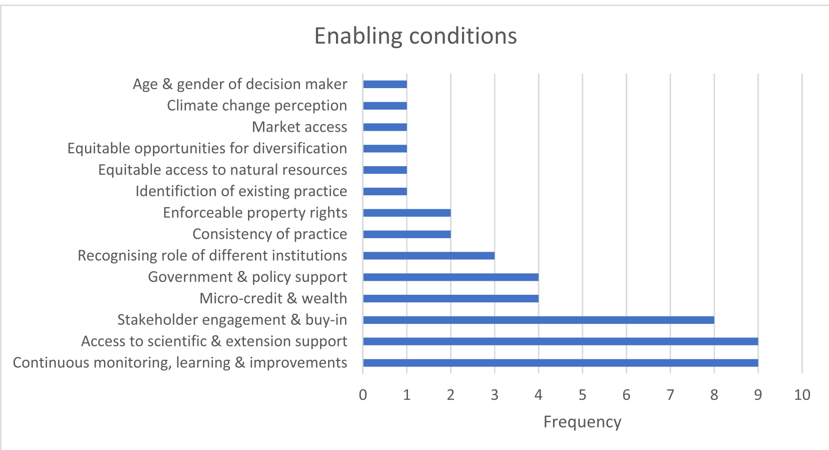

Fig. 2. Enabling conditions for knowledge integration thematically analysed from 21 papers as indicated in Appendix A.

successful knowledge integration for resilience (ADO et al., 2020; MUGARI et al., 2020; NDIRITU, 2020; NG'ANG'A et al., 2020, OSBAHR et al., 2008). Additionally, equal access to natural resources was reported by SALLU et al. (2010) as being a significant enabling condition for knowledge integration for livelihoods resilience in rural Botswana. In their study, REED et al. (2007) suggest that common property regimes for rangeland management are necessary for adaptation strategies to be effective. The continuous and consistent use of coping and adaptation strategies based on local knowledge, not only at periods of crisis, was important for validating the efficacy of such strategies and successfully integrating it into scientific knowledge for farmers' resilience (BUNCLARK et al., 2018).

Some households combined local knowledge, assets, and government support to increase resilience (SALLU et al., 2010). ANTWI-AGYEI et al. (2015) reported that availability of collateral to access credit and land title for migrants and women in Ejura Sekyedumase and Bongo districts respectively influenced choices of adaptation strategies. Uncertainty about income remittances from husbands who migrated to South Africa also made women in Mozambique cope through casual employment (ERIKSEN and SILVA, 2009). BUNCLARK et al. (2018)'s study in Burkina Faso also found that the availability of water harvesting techniques promoted the continuous adoption of climate-smart practices for SSA smallholders.

The reorganisation of social institutions is invaluable and required to provide the 'right' set of institutional support for local and scientific knowledge integration (KALAME et al., 2011; OSBAHR et al., 2008; REED et al., 2007; SALLU et al., 2010). Also, livelihoods resilience could be achieved if the importance of informal and formal institutions is acknowledged (SALLU et al., 2010). Provision of market infrastructure was equally found to be instrumental to the successful integration of local and scientific knowledge for adaptation to climate change by farmers in Afar Region, in Ethiopia (TREYDTE et al., 2017). The provision of market facilities for livestock sales has been shown to enable these Ethiopian farmers to accept livestock breeding programmes promoted by extension agents (TREYDTE et al., 2017). Hence, the importance of identifying and understanding the enabling conditions that promote knowledge integration.

4. Discussion

4.1. Climate change adaptation and coping knowledge sources

This paper has assessed the existing types and sources of information used by farmers in SSA drylands and the enabling conditions for the integration of local and scientific knowledge types for climate change coping and adaptation strategies that are important for farmers in SSA drylands. Understanding farmers' sources of adaptation knowledge is important since some farmers only use their local knowledge to adapt without a need for externally based scientific support provided by extension agents. Some scholars of SSA drylands argue that the use of local knowledge promotes resilience to climate and environmental changes as farmers can prepare and cope based on previous experiences of extreme weather conditions (e.g., BATTERBURY and MORTIMORE, 2013; GUODAAR et al., 2021). Our review reveals that farmers from thirteen out of the seventeen SSA countries considered in this study have used an array of strategies based on local knowledge to respond to climate and environmental changes (e.g., seed storage, migration, and remittances). However, some of these farmers-mainly the poor and women farmers from the remaining four SSA countries have shown to be more vulnerable amidst harsh environmental, climate and economic conditions (DIXON et al., 2014; LEAL et al., 2017; MORTIMORE, 2005b).

Our analysis indicates that some of the key local knowledge-based coping strategies identified in this study include migration of people or moving livestock to "greener pasture". The limitation of these important local knowledge-based coping strategies is that it affects farmers' choices of responses to shocks, leading to the search for alternative strategies such as the reduction in herd sizes and rainwater harvesting techniques which might improve resilience to adverse climate conditions (BROTTEM and BROOKS, 2018; LEAL et al., 2017).

Other farmers overcome the limitation on their local knowledge by using scientific knowledge from extension services (e.g., altering planting time, use of early maturing and drought-tolerant crop varieties) alone. The use of drought-tolerant and early maturing crop varieties was found to be the most important strategy across the studies due to the high frequency of occurrence of the adaptation strategy (Table 3). This implies that drought and rainfall variability remain the key challenge of climate change, especially in the dry areas of SSA. Scientific-based adaptation strategies are argued to be a 'one-size-fits all' approach and supply rather than demand-driven, leading to the low adoption by local farmers (MCGUIRE and SPERLING, 2008). Thus, scientific adaptation strategies alone may not be trusted by local farmers (KHAILA et al., 2015) with the likelihood of exposing farmers to more impacts of climate change and attendant implications on food security and livelihoods sustainability.

While both locally based and scientifically based knowledge types have separately played crucial roles in helping farmers cope or adapt to drylands' challenges, these two types of knowledge when used individually have gaps, as articulated by REED et al. (2007). Thus, the combined use of locally and scientifically based knowledge by farmers from West Africa (Burkina Faso, Ghana, Mali), Southern Africa (Botswana, Mozambique, and South Africa), and Eastern Africa (Ethiopia, Kenya, and Uganda) proved invaluable. Therefore, farmers' choices of sources of knowledge are likely to be linked to the peculiar climate challenges of the regions and countries of study.

4.2. Enabling conditions for knowledge integration

Contrary to using scientific knowledge alone, the integration of both knowledge sources has been more successful as knowledge integration addresses location-specific challenges, farmers' diverse socio-economic, cultural, environmental, and climatic conditions. This emphasises the need to understand the enabling conditions which allow stakeholders (e.g., farmers, extension agents, and researchers) to share, absorb, improve, and implement the strategies for successful adaptation knowledge integration. In fact, participatory approaches to tackling climate change are argued to lead to trust-building, closeness, reduced conflict among the stakeholders (DAPILAH et al., 2021; REED et al., 2018), farmers' increased learning, and acceptance of externally supplied strategies (KHAILA et al., 2015). This implies that scientific knowledge is crucial under changing climatic conditions that have not previously been experienced (KALAME et al., 2011; TREYDTE et al., 2017).

The review also showed the invaluable role of the right set of institutional support, especially the reorganisation of social institutions, which according to OSBAHR et al. (2008), is the prerequisite for required local and scientific knowledge integration (OSBAHR et al., 2008). Also, the provision of market facilities for the sale of livestock enabled farmers to accept livestock breeding programmes promoted by extension agents (TREYDTE et al., 2017).

Successful integration of location-specific knowledge in a participatory way has been shown to lead to degradation reduction or adaptation (REED et al., 2007). The case of Botswana and South Africa can be used as successful examples of the use of these enabling conditions for integrating coping and adaptation knowledge (NDHELEVE et al., 2017; REED et al., 2007; SALLU et al., 2010).

Stakeholder (farmer) engagement and buy-in were very significant enabling conditions reported for integrating knowledge for resilience (JELLASON et al., 2020; NDHELEVE et al., 2017; TOTIN et al., 2018). This underscores the value of participatory collaboration between local farmers, extension agents, researchers, and development actors from different backgrounds to achieve a successful adaptation (BUNCLARK et al., 2018). In corroboration with SIETZ and VAN DIJK (2015)'s study on soil water conservation in West Africa, our analysis suggests that continuous learning and improvements are key to successful knowledge integration. The latter has been found to be a significant enabling condition for knowledge integration. Moreover, as reported by BELLE et al. (2017), this enabling condition is useful in reducing susceptibility to drought so that farmers can prepare and act. Hence, the need to understand the strengths of the different knowledge sources in order to achieve successful outcomes (RAYMOND et al., 2010).

Also, there is still a need for governmental and non-governmental institutions and policymakers to look at farmers' knowledge for its merit in helping farmers survive over generations. Stakeholders need to understand, acknowledge, validate, and promote the use of local knowledge by integrating it with scientific knowledge and as part of policy formulation, as supported by SALITE (2019) and TENGÖ et al. (2014). More importantly, farmers should have a role in policy design since they know better and have experienced the changes in the environment and climate over generations and have their own knowledge, experiences, and perspectives to explain and respond to the changes, based on their needs and preferences. Such measures will aid in the design of more tailored, context-specific, and feasible adaptation strategies.

5. Conclusion

Local and scientific knowledge for coping and adaptation were found to be used separately and, in some cases, integrated to overcome the limitations of each knowledge type and to increase the likelihood of success of the coping and adaptation strategies implemented. Despite examples of the success of knowledge integration, we conclude that much still needs to be done in order to increase the dissemination, assimilation and adoption of knowledge integration. It is crucial to understand the important role of knowledge integration and identify the enabling conditions. As the population rapidly grows under an uncertain and changing environment and climate, and with a growing demand for food, there is a need to use and manage resources in a more sustainable way. This need is particularly urgent in drylands due to the various crucial ecosystem services they provide to people globally, especially in SSA where agriculture is often rain-fed. Thus, investment in more innovative and diversified adaptation approaches that draw on multiple knowledge systems cannot be overemphasized.

Author contribution statement

Nugun P. Jellason (NPJ): Conceptualization, Data curation, Formal analysis, Investigation; **NPJ, Daniela Salite (DS), Chukwuma C. Ogbaga (CCO):** Methodology; Project administration; **DS**: Validation; **NPJ**: Visualization, Writing - original draft; **NPJ, DS, CCO**: Writing - review & editing.

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Declaration of competing interest

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Appendix A. Supplementary data

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