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Climate change adaptation options to inform planning of agriculture and food systems in The Gambia: A systematic approach for stocktaking

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Identifying and assessing adaptation options are key pre-requisite steps to adaptation prioritization and effective adaptation planning. In this paper, we presented a systematic approach for adaptation stocktaking, combining a systematic mapping and an outcome-oriented and evidence-based assessment, illustrated using the case of The Gambia. This study systematically mapped 24 adaptation options that can potentially inform adaptation planning in The Gambia agriculture and food systems and assessed how the identified options contribute to the pillars of Climate-Smart Agriculture. Because of the paucity of evidence sources from The Gambia, we collated evidence from both The Gambia and the West Africa region. We found that many of the documented options, such as climate-resilient crop varieties, crop diversification, climate information use, and weather indexed-based insurance have the potential to increase agricultural productivity and income while building resilience to climate change. While several options, such as soil and water conservation practices can positively contribute to climate change mitigation, others such as manure and inorganic fertilizers can have no or negative impacts on mitigation. Agroforestry practices and System of Rice Intensification have the potential to make a triple impact. The paucity of evidence from The Gambia and the highly contextual and differential impacts of the identified adaptation options underscore the importance of careful consideration of barriers and enablers when developing and deploying policy and interventions to sustainably increase productivity and income while building resilience to climate risks and reducing GHGs emissions. Stakeholder engagement and participatory research action are crucial in selecting and testing the priority adaptation options which can maximize their potentials in specific agricultural and food system contexts, such as in The Gambia. Because of the heterogeneity in household vulnerability and socioecological circumstances, targeting options to the right contexts will also be crucial to avoid maladaptation. We highlighted key knowledge gaps in the understanding of the effectiveness and feasibility of the identified adaptation options in The Gambia. Beyond The Gambia, the approach can also be useful for and replicated in other least developed countries in the West African region, that are currently developing their National Adaptation Plan.

KEYWORDS

Climate-Smart Agriculture (CSA), resilience, mitigation, Gambia, adaptation planning, effective adaptation, national adaptation plan, systematic review

Introduction

Adaptation is increasingly recognized as a crucial component of the global response to climate change, particularly following the Paris Agreement, which articulates a global adaptation goal and a mandate for all parties to undertake and assess adaptation progress (Berrang-Ford et al., 2019; Singh et al., 2022). Undertaking and documenting adaptation progress is crucial to inform adaptation and mitigation planning and future commitments in National Adaptation Plans (NAPs) and Nationally Determined Contributions (NDCs) (Berrang-Ford et al., 2019; Singh et al., 2022). In developing and least developed countries (LDCs), where compounded or cascading climate risks could interact with and limit achieving the Sustainable Development Goals (SDGs), adaptation is urgent (Hoegh-Guldberg et al., 2019; Roy et al., 2022; Simpson et al., 2022). Adaptation is even more imperative in the most vulnerable countries, such as The Gambia (Camara et al., 2021), where climate-sensitive sectors such as agriculture, play a crucial role in economic development (Tinta, 2017; MECCNAR, 2021).

Because climate change risks magnify development challenges for LDCs, the 2010 Cancun Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) established the NAP process as a way to facilitate effective adaptation planning in LDCs and other developing countries (LEG., 2012). NAPs aim to identify medium- and long-term adaptation needs and enable countries to develop and implement strategies to reduce vulnerability to the impacts of climate change, to facilitate the integration of climate change adaptation, in a coherent manner, in the broader context of sustainable development planning (LEG., 2012). Furthermore, NAPs are intended to coordinate national adaptation efforts by providing guidance to government agencies, communities, the private sector, and other relevant stakeholders (LEG., 2012; Woodruff and Regan, 2018).

One of the recommended steps for the formulation of the NAP, by the Least Developed Countries Expert Group (LEG), is the stocktaking, which is intended to identify available information on climate change impacts, vulnerability and adaptation, and review and appraise adaptation options (LEG., 2012). Furthermore, this national stocktake can also help LDCs to meet the Paris Agreement's requirement of identifying, assessing and reporting on adaptation progress by all parties to the UNFCCC. While the LEG has provided guidance and recommendations on each step of the NAP process, based on the guiding principles (LEG., 2012), a practical approach or method to systematically take stock of existing knowledge and information on climate change impacts, vulnerability and adaptation, and review and appraise adaptation options is still lacking. Thus, each LDC follows its own path for synthesizing existing knowledge to inform NAP formulation and adaptation planning, which does not allow a cross-country assessment of quality planning (Woodruff and Regan, 2018).

In addition, with the Paris agreement requiring all parties to assess adaptation progress, including reviewing the effectiveness of adaptation to inform climate action planning and commitments (Berrang-Ford et al., 2019; Singh et al., 2022), how to assess adaptation effectiveness became crucial (Berrang-Ford et al., 2021; Singh et al., 2022). In a recent analysis, Singh et al. (2022) illustrated how different normative views on adaptation outcomes, arising from different epistemological and disciplinary entry points, can lead to very different interpretations of adaptation effectiveness. Furthermore, innovative methods for synthesizing the evidence on diverse and rapidly expanding adaptation knowledge are still needed (Berrang-Ford et al., 2021).

Using the case of The Gambia, one of the most ambitious LDC, with track record of national and international leadership on climate action (Camara et al., 2021; MECCNAR, 2021), this study presents a systematic approach for stocktaking and appraisal of adaptation options in agriculture and food systems to provide evidence base that would enable informed decision-making and effective adaptation planning. The proposed approach is composed of two parts: i) identification of adaptation options, using a three-step systematic mapping of adaptation options, and ii) evidence-based assessment of the effectiveness of the identified adaptation options following an outcome-based framing of adaptation effectiveness. The operationalization the Gambian's ambitious climate action commitments in agriculture and food systems could build on prior knowledge of adaptation technologies and practices that could be effective and relevant to the context of Gambian agriculture and food systems. This knowledge can also inform adaptation planning and The Gambia's commitments in NDC (currently being revised) and NAP (currently in the preparatory phase). Beyond The Gambia, the approach can also be useful for and replicated in other countries in the West African region, that are currently in the preparing their NAP process. It can also enable LDCs reporting of adaptation progress under UNFCCC.

Using a systematic approach, we identified and synthesized climate change adaptation options relevant for The Gambian agriculture and food systems. Specifically, we mapped any adaptation option that has been reported or implemented in The Gambia agriculture and food systems following a three-step review process (Figure 1). We then analyzed how the identified options contribute to the pillars of Climate-Smart Agriculture (CSA). CSA is an approach for transforming and reorienting agricultural systems to support food security under the new realities of climate change (Lipper et al., 2014; Totin et al., 2018). It is defined by three main objectives: (i) increasing agricultural productivity to support increased incomes and food security (productivity pillar); (ii) adapting and building resilience to climate change across scales (from farm to nation; adaptation pillar); and (iii) reducing greenhouse gas emissions and increasing carbon sinks (mitigation pillar; Lipper et al., 2014; Totin et al., 2018).

Materials and methods

Identification of adaptation options

We adopted a mixed methods approach, combining several steps, to identify the adaptation options that could be relevant for The Gambian agriculture and food systems (Figure 1). By "relevant", we mean adaptation options that can be appropriate in the contexts or circumstances of agriculture and food systems in The Gambia; these include any adaptation options that has been implemented or reported as implemented in The Gambia in the documents identified following the different steps described in the section (Figure 1).

First, we reviewed and included the adaptation options analyzed in the Climate-Smart Agriculture (CSA) Profile of The Gambia (FAO et al., 2018). The CSA profile gives an overview of the agricultural challenges in the country, and how CSA can help adapt to and mitigate climate change in agriculture and food systems (FAO et al., 2018). It also provides a snapshot of baseline information to initiate discussion about entry points for investing in CSA at scale. In addition, adaptation options analyzed in The Gambia CSA profile have been completed and extended with adaptation options from the Evidence for Resilient Agriculture (ERA) database[1] ERA provides a comprehensive synthesis of the effects of CSA technologies and practices on key indicators of productivity, resilience and mitigation (Nowak and Rosenstock, 2020).

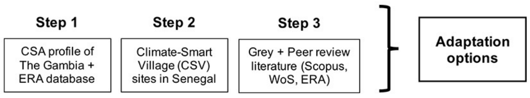

FIGURE 1
Steps for identification of adaptation options.

Second, we reviewed and selected adaptation options tested through the Climate-Smart Village (CSV) approach (Aggarwal et al., 2018). The CSV approach has been developed and implemented by the CGIAR Research Program on Climate Change Agriculture and Food Security (CCAFS) across Asia, Africa, and Latin America to generate evidence on the effectiveness of CSA technologies (Aggarwal et al., 2018). The CSV approach is a mean of conducting agricultural research for development that robustly tests institutional and technological innovations for dealing with climatic risks and challenges for agriculture using participatory methods (Aggarwal et al., 2018). As The Gambia shares many socio-ecological and cultural features with Senegal, we considered adaptation options tested in the CSV sites in Senegal (Sanogo et al., 2017).

Third, we identified additional adaptation options from gray and peer reviewed literature on climate change adaptation in The Gambia. Gray literatures were identified through Google search using search terms related to climate change adaptation and The Gambia and included reports from institutions such as FAO, ActionAid NGO, The Gambian NDC, Governments reports and documents. We also conducted a systematic review to identify relevant peer reviewed publications in two databases: Scopus and Web of Science (WoS). We searched in Title, Abstract and Keywords of publications for combined the search terms related to climate change ("global warming" OR "climat* change" OR "climat* variability" OR "climat* warming"), adaptation ("adapt*" OR "risk reduc*" OR "risk manag*" OR "resilien*" OR solution* OR respons*) and "The Gambia". Publications in sectors other than agriculture and food systems (e.g., ecology, conservation, tourism, parks and wildlife management) or in which no data were not collected

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[1] https://era.ccafs.cgiar.org/

in The Gambia were excluded. Publications on mitigation with no mention of adaptation and outside agriculture and food systems were also excluded. The full texts of relevant papers were reviewed, and adaptation options were extracted. The list of the gray literature reviewed and the relevant publications are presented in Supplementary materials 1 and 2 respectively.

Assessing effectiveness of the identified adaptation options

We followed an outcome-based or goal-oriented framing of effective adaptation (Singh et al., 2022), with the contributions to three CSA pillars as the outcome or goal to achieve with the implementation of adaptation options in agriculture and food systems (Thornton et al., 2018). To assess the climate-smartness of the identified adaptation options, we explored how the options contribute, positively or negatively, to the three CSA pillars: (1) increasing agricultural productivity and incomes; (2) adapting and building resilience to climate change; (3) and reducing and/or removing GHG emissions. We reviewed peer review literature to assess whether there was an association documented in the peer reviewed literature between the CSA pillars and each of the adaptation options. We used indicators of each CSA pillar: productivity (yield and income), adaptation (soil, water and risk management), and mitigation (energy, carbon and other GHGs emissions). For each of the adaptation options we recorded whether the effects on each of the CSA pillars documented in the peer reviewed literature were predominantly positive, predominantly negative, or mixed. As climate-smartness is context specific and not an innate property (Sova et al., 2018; Thornton et al., 2018), we provided the overall direction of the effect (positive, negative or mixed) across the literature and not the magnitude of effects. Following Kuyah et al. (2021), we also complemented the analysis with an expert knowledge-based assessment of the importance of identified practices for CSA pillars. The same approach[2] was used in developing the CSA profile of The Gambia (FAO et al., 2018) and prioritizing CSA options for investments in Mali (Andrieu et al., 2017). It is also one of the suggested approaches for setting priorities in CSA research (Thornton et al., 2018). A similar approach was also used to assess the contributions of selected agronomic practices to sustainable intensification of agricultural production systems in sub-Saharan Africa (Kuyah et al., 2021). To identify relevant peer review literatures which provide evidence for assessing the contributions of each of the identified options to the CSA pillars, we conducted a series of systematic search in Scopus and Web of Science (WoS). In each database, we searched in Title, Abstract and Keywords of publications for combined the search terms related to each identified adaptation options (see Supplementary material 3 for search terms used for each option) and "The Gambia". Publications outside agriculture and food systems and/or with no data on the indicators of the three CSA pillars were excluded. The full texts of relevant papers were reviewed to assess how each of each option contribute to the CSA pillars. Supplementary material 3 presented the list of relevant papers reporting empirical study from The Gambia. As there was not enough literature from The Gambia to provide evidence base for assessing the contribution of some of the adaptation options to the CSA pillars (see Supplementary material 3), we used evidence from literature outside The Gambia. We used evidence from the ERA database and additional peer reviewed literature, reporting findings from West Africa or sub-Saharan Africa, to analyze the potential of these practices and technologies to deliver on one or more of the three CSA pillars. Although the selection of those additional peer review literature supporting the effects of some of the options on CSA pillars was not systematic, an assessment of the design of the studies served as indirect proxy of the strength of the evidence. Supplementary material 4 presents the list of the adaptation options and the literature from West Africa or sub-Saharan Africa supporting the contribution of each option to the three CSA pillars.

Results and discussion

Screening and identification of adaptation options

A total of 11 documents from the gray literature (including reports from institutions such as FAO, ActionAid NGO, The Gambian NDC, Governments reports and documents) were identified and reviewed to extract adaptation options. The scoping search of peer reviewed literature resulted in 53 articles from Scopus and WoS. Nine (09) additional publications were identified from the ERA database and added to the list. After removing duplicates and screening for eligibility for the study based on the title and abstract, 54 articles remained. After full article screening, a total of 21 articles met our inclusion and exclusion criteria (Figure 2).

Following the three-step review process (Figure 1), a total of 24 adaptation practices and technologies were identified for agriculture and food system adaptation in The Gambia (Table 1). The adaptation options were grouped into seven adaptation categories (Table 1), following Wiederkehr et al. (2018), and included crop diversity use and management practices, soil and nutrient management, soil and water conservation, agroforestry options, livestock-based practices, agro-climatic information and services, and livelihood diversification options. A short description of each option is

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[2] Additional details on CCAFS CSA Prioritization Framework is available on: https://csa.guide/csa/targeting-and-prioritization.

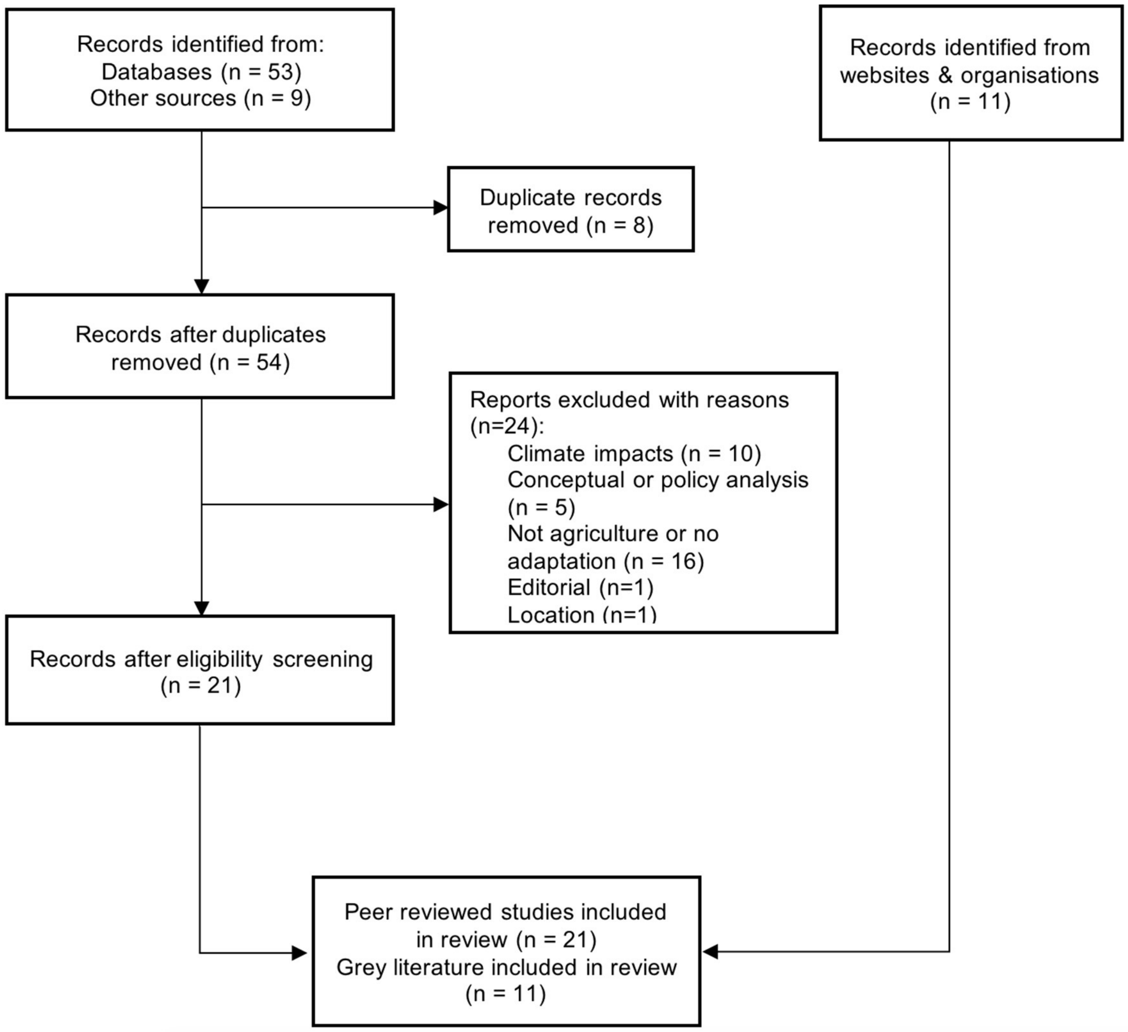

FIGURE 2
PRISMA diagram of literature screening.

presented in Supplementary material 4. Table 2 summarizes how each adaptation option delivers on one or more of the three CSA pillars. A short description of the climate-smartness of each option and supporting references are also presented in Supplementary material 4. Detailed descriptions are published elsewhere (Segnon et al., 2021b).

Climate-smartness of the identified adaptation options

Crop diversity use and management

In sub-Saharan Africa, many farmers take advantage of the differential effects that climate conditions might have on different crops and varieties to adapt to climate variability (Fisher et al., 2015; Segnon et al., 2015). Although the use of climate-resilient crops or crop varieties, crop diversification, changing planning date and IPM are common reported adaptation practices in The Gambia (Sanneh et al., 2014; Amuzu et al., 2018; FAO et al., 2018; Bagagnan et al., 2019; Sonko et al., 2020, 2022), empirical assessment of the outcomes of these adaptation options in The Gambia context is, however, very limited. From the systematic searches, only five studies assessing the outcomes of the use of climate-resilient crops or crop varieties were identified (Dibba et al., 2012, 2017; Diagne et al., 2013; Van Der Geest and Warner, 2014; Sonko et al., 2022). Four studies assessed the outcomes of IPM strategies (Carson, 1988a,b, 1989; Cockfield, 1992), and only one study assessed the impacts of crop diversification (Aubee and Hussein, 2002). No relevant studies were identified to provide evidence on the outcomes of changing planting dates to manage climate risks (Supplementary Table 4).

TABLE 1 Technologies and practices relevant for agriculture and food systems adaptation in The Gambia.

Adaptation categories	Adaptation practices and technologies	Sources
Crop diversity use and management	Improved or climate-resilient crop varieties	FAO et al. (2018), Bagagnan et al. (2019), Sonko et al. (2020), Amuzu et al. (2018)
	Crop diversification	Sonko et al. (2020), Sanneh et al. (2014), Amuzu et al. (2018), Ceesay et al. (2006), Anderson (2017)
	Changing planting date	Ceesay et al. (2006), Sonko et al. (2020)
	Integrated pest management	FAO et al. (2018), Sonko et al. (2020), Sanneh et al. (2014)
Soil and nutrient management	Composting	FAO et al. (2018), Bagagnan et al. (2019)
	Manure	Bagagnan et al. (2019), ERA database
	Mulching	FAO et al. (2018), Bagagnan et al. (2019), ERA database; Ashrif and Thornton (1965)
	Inorganic fertilizers	Bagagnan et al. (2019)
	Conservation agriculture	FAO et al. (2018), Amuzu et al. (2018), Sonko et al. (2020), Bagagnan et al. (2019)
	Crop rotation	Sonko et al. (2020), Bagagnan et al. (2019), Amuzu et al. (2018), Ceesay et al. (2006)
	Intercropping	FAO et al. (2018), ERA database; Bagagnan et al. (2019)
Soil and water conservation	Contour bunds/farming	FAO et al. (2018), Sonko et al. (2020), Wright et al. (1991), Doumbia et al. (2009), Anderson (2017)
	Zaï or planting pits	Amuzu et al. (2018)
	System of rice intensification	FAO et al. (2018), Ceesay (2011), Bagagnan et al. (2019), Danso and Morgan (1993a,b)
	Irrigation	FAO et al. (2018), Sanneh et al. (2014), Manka (2014)
Agroforestry systems	Farmer managed natural regeneration (woodlot)	FAO et al. (2018), Amuzu et al. (2018), ERA database; Sonko et al. (2020)
	Alley farming	Sonko et al. (2020), ERA database
Livestock-based systems	Switching to drought-tolerant animal species	Amuzu et al. (2018), Olaniyan (2017)
	Feed supplementation or addition	ERA database; Akinbamijo et al. (2003), Olaniyan (2017), Little et al. (1991a,b)
	Stock/Herd size reduction	Olaniyan (2017)
Agro-climatic information and services	Climate information and agro-advisories services use	Sanogo et al. (2017), Amuzu et al. (2018), Anderson (2017)
	Microfinance and weather index-based insurance	Sanneh et al. (2014), Greatrex et al. (2015), Delavallade et al. (2015)
Livelihood diversification	Livelihood diversification	Ceesay et al. (2006), Amuzu et al. (2018), Van Der Geest and Warner (2014), van der Geest and Warner (2015), Anderson (2017)
	Migration	Yaffa (2013), van der Geest and Warner (2015), Sonko et al. (2020)

Empirical studies showed that the adoption of improved drought-resistant rice varieties such as NERICA significantly improved productivity-related indicators such as rice yields and income (Dibba et al., 2012; Diagne et al., 2013) and household food security in The Gambia (Dibba et al., 2017). Beyond the Gambia, empirical evidence from 16 sub-Saharan African countries also revealed that the adoption of improved rice varieties improved farmer income and food security, and reduced poverty (Arouna et al., 2017). Adoption of the drought tolerant maize varieties (DTMVs) disseminated across 13 African countries increased maize yields and reduced yield variability and exposure to risk of crop failure among adopters (Wossen et al., 2017). Productivity increase and risk reduction resulting from adoption of DTMVs led to a reduction in the incidence of poverty and in the probability of food scarcity (Wossen et al., 2017). A recent assessment of adoption of improved groundnut varieties (a key crop in The Gambia) in semi-arid West Africa also found an increased household income and food security indicators, and poverty reduction as a result of adopting improved groundnut varieties (Lokossou et al., 2022).

Simulated adoption of drought tolerant maize seeds could increase yields by up to 25% under climate change conditions in Africa by 2050 compared with expected yields with current varieties (Islam et al., 2016). By decreasing the vulnerability of farm households to climate risks though increasing production and reducing exposure to risk, resilient crop and crop varieties also reduce the need for harmful post-failure coping strategies (Fisher et al., 2015; Wossen et al., 2017). This highlights that adoption of climate-resilient crop varieties and crops contributes

TABLE 2 Climate-smartness of the identified adaptation options.

Adaptation options	Productivity	Adaptation	Mitigation	References
Improved or climate-resilient crop varieties	+	+	+/−	Wossen et al. (2017), Martey et al. (2020), Arouna et al. (2017), Ogada et al. (2020), Islam et al. (2016), Zougmoré et al. (2018), Cacho et al. (2020), Lokossou et al. (2022)
Crop diversification	+	+	+/−	Di Falco et al. (2010), Segnon et al. (2015), Tesfaye and Tirivayi (2020), Anderson (2017)
Changing planting date	+	+	na	Sonko et al. (2020), Martey et al. (2020), Nyagumbo et al. (2017), Fentie and Beyene (2019), Traore et al. (2017), Muluneh et al. (2017)
Integrated pest management	+	+	+/−	Himmelstein et al. (2017), Murrell (2017)
Composting	+	+	+/−	Anderson (2017), FAO et al. (2018), ERA database
Manure	+	+	−	Du et al. (2020), Kichamu-Wachira et al. (2021), ERA database
Mulching	+	+	+	Ashrif and Thornton (1965), Li et al. (2021), Mhlanga et al. (2021), Kichamu-Wachira et al. (2021)
Inorganic fertilizers	+	+	−	ERA database; Traore et al. (2014)
Conservation agriculture	+	+	+	Bayala et al. (2012), Lahmar et al. (2012), Partey et al. (2018), Araya et al. (2021), Corbeels et al. (2020), Kichamu-Wachira et al. (2021), Michler et al. (2019), Nyagumbo et al. (2020), Komarek et al. (2021), Bai et al. (2019), Mhlanga et al. (2021)
Contour bunds/farming	+	+	+	Zougmore et al. (2014), Partey et al. (2018), Anderson (2017), Birhanu et al. (2020), Wright et al. (1991), Doumbia et al. (2009), Zougmoré et al. (2011)
Zaï or planting pits	+	+	+	Zougmore et al. (2014), Partey et al. (2018), Lahmar et al. (2012), Garrity et al. (2010)
Irrigation	+	+	+/−	Manka (2014), FAO et al. (2018), Partey et al. (2018), Woltering et al. (2011), Wanvoeke et al. (2016), Muluneh et al. (2017)
System of rice intensification	+	+	+	Ceesay et al. (2006), Thakur et al. (2016), Thakur and Uphoff (2017), Graf and Oya (2021), Ceesay (2011), Thakur et al. (2020), Hasanah et al. (2019)
Agroforestry systems	+	+	+	Garrity et al. (2010), Bayala et al. (2014), Mbow et al. (2014), Partey et al. (2018), Bado et al. (2021), Kuyah et al. (2019), Muchane et al. (2020), Binam et al. (2015), Weston et al. (2015), Binam et al. (2017)
Switching to drought-tolerant animal species or breeds	+	+	+	Ogada et al. (2020), Acosta et al. (2021), Hristov et al. (2013), Grossi et al. (2019)
Feed supplementation or addition	+	+	+	Rojas-Downing et al. (2017), Little et al. (1991a,b), Akinbamijo et al. (2003), Gerber et al. (2013), Hristov et al. (2013), Herrero et al. (2016), Grossi et al. (2019)
Stock size management	+	+	+/−	Gaughan et al. (2019), Hristov et al. (2013)
Climate information and agro-advisories services use	+	+	na	Diouf et al. (2020), Dayamba et al. (2018), Ouedraogo et al. (2018), Djido et al. (2021a,b)
Microfinance and weather indexed-based insurance	+	+	na	Greatrex et al. (2015), Delavallade et al. (2015), Bertram-Huemmer and Kraehnert (2018), Gebrekidan et al. (2019), Haile et al. (2020), Chantarat et al. (2013), Jensen et al. (2016), Matsuda et al. (2019), Noritomo and Takahashi (2020)
Livelihood diversification	+	+	na	Anderson (2017), Rao et al. (2020), Sonko et al. (2020), Yaffa (2013)
Migration	+/−	+/−	na	Rao et al. (2020), Sonko et al. (2020), Maharjan et al. (2020), Banerjee et al. (2018), Sulemana et al. (2019), Vinke et al. (2020), Pandey (2019), Atiglo et al. (2020), Adams (2011), Ajaero et al. (2018), Yaffa (2013)

+, *predominantly positive contribution;* −, *predominantly negative contribution;* +/−, *mixed contribution; na, no evidence.*

to not only improve productivity but also resilience of cropping and farm systems to climate risks.

As rainfall patterns in The Gambia have become more erratic, crop and cropping systems diversification will be particularly important in the future. Currently, on-farm diversification of crop and crop varieties help farmers to spread the risk of crop failure and reduce losses in The Gambia (Van Der Geest and Warner, 2014; Anderson, 2017). An increase in food security and effective adaptation to climate change were also reported as results of implementation of on-farm crop diversification (Anderson, 2017). Households that has planted drought-resistant crop varieties were more successful in avoiding loss and damage from the 2011 drought in The Gambia (Van Der Geest and Warner, 2014). In The Gambia, Fonio is a climate-smart and early-maturing cereal crop, with high nutritive value and ability to withstand dry spells Sonko et al. (2022), a crucial trait for managing climatic risks. Sesame was another climate-smart crop, which played in a key role in building household resilience following the drought of the 1980s in The Gambia (Aubee and Hussein, 2002). Beyond The Gambia, adoption of multiple climate-resilient crops has been shown to significantly improve household income, which resulted in household asset accumulation (Ogada et al., 2020). The effects of crop diversification toward reducing crop failure and increasing production become stronger on degraded and less fertile land and when rainfall level is lower (Di Falco et al., 2010). In addition, diversification of field plots can take advantage of spatial variability in rainfall in drought-prone rainfed systems (Fisher et al., 2015; Segnon et al., 2015).

Although improved and resilient crop varieties have been shown to be climate-smart, there are concerns on increased GHGs emissions associated with the use of fertilizers and also the high input and supply costs which often reduces the adoption potential of smallholder farmers (Zougmoré et al., 2018). However, no empirical evidence currently exists on the effects of adoption of climate-resilient crops and crop varieties on the mitigation pillar in the Gambian context.

In The Gambia, limited availability of high quality seeds and limited number of seed companies represent key barriers to widespread adoption of improved climate-resilient crop varieties (FAO et al., 2018). Indeed, lack of access to seeds was a key barrier limiting adoption of drought-tolerant NERICA varieties in The Gambia (Dibba et al., 2015). However, the economic benefits of adapting seed systems to current and future climate shocks are substantial. Based on nationally representative data from Malawi and Tanzania, Cacho et al. (2020) estimated the benefits from adopting climate-resilient varieties to range between 984 million and 2.1 billion USD over 2020–2050. This estimate illustrates the benefits of establishing and maintaining a flexible national seed sector and providing incentives to smallholder farmers to adopt climate-resilient crop varieties (Cacho et al., 2020).

Changing planting date to adjust to the erratic rainfall pattern helps Gambian farmers to reduce risks of crop failure (Sonko et al., 2020). No relevant studies were identified to provide evidence on the outcomes of changing planting dates to manage climate risks in The Gambia. Optimum planting dates improve crop yield and reduce yield variability (Nyagumbo et al., 2017). Adoption of row planting also results in increase maize yield (Martey et al., 2020), household income and food security (Fentie and Beyene, 2019).

Climate change is altering the distribution, incidence and intensity of animal and plant pests and diseases as well as invasive and alien species (FAO et al., 2018). Climate-smart pest management practices common in The Gambia include traditional and physical approaches (FAO et al., 2018). The Integrated Pest Management (IPM) approach is also widespread following its introduction by the Pest Management Unit of the Ministry of Agriculture (FAO et al., 2018). Millet-groundnut rotation was reported as an example of efficient cultural control approach for managing Striga populations in farmer fields (Carson, 1988a). Intercropping of sorghum and groundnuts was also effective in reducing density of Striga in sorghum field in The Gambia (Carson, 1989). The use of groundnut oil in combination with bruchid-resistant variety was reported to be effective as chemical pesticides for protection stored cowpea grain in The Gambia (Cockfield, 1992). Evidence from a meta-analysis indicated that IPM practices can effectively reduce pest pressure and increase crop yields in African farming systems (Himmelstein et al., 2017). Promoting IPM in The Gambia as well as in other African countries should go in hand with regulating and policy enforcement of pesticides import and uses, as fraudulent pesticides are widespread, compromising human and environmental health and safety (Haggblade et al., 2022).

Soil and nutrient management practices

Several nutrient management practices were identified through the three-step inventory (Figure 1) as adaptation options in The Gambia. These include the use of compost, manure, mulching, inorganic fertilizers and conservation agriculture practices (Amuzu et al., 2018; FAO et al., 2018; Bagagnan et al., 2019; Sonko et al., 2020, 2022). The use of chemical fertilizers was reported as a preferred adaptation option by farmers, even though inorganic fertilizer is very expensive (Bagagnan et al., 2019). Following the systematic search of the evidence sources supporting the contribution of the options to the CSA pillars, we found three (03) studies assessing the outcomes of inorganic fertilizer use (Eldon et al., 2020; Raes et al., 2021; Sonko et al., 2022), two (02) studies on mulching (Ashrif and Thornton, 1965; Eldon et al., 2020), and one study for each of use of compost, manure (Eldon et al., 2020). No study assessing the outcome of intercropping, crop rotation, and conservation agriculture (CA) as a system was available (Supplementary Table 4).

Composting and compost use have been reported to strengthen cropping systems' resilience to drought in The

Gambia (Anderson, 2017). A simulation analysis indicated that composting could reduce solid waste in the Gambia by 64% in the next 25 years, contributing to GHGs emissions from inappropriate disposal and management of municipal solid waste (Jassey et al., 2021).

On-farm research trials across The Gambia and Senegal testing effects of inorganic fertilizer, manure, mulching showed that all the treatments have positive effects on yields of sorghum, millet, groundnut, rice, maize and cowpea (Eldon et al., 2020). Compared to mineral fertilizer, manure application increased yield, with effects more pronounced in warm and/or humid climates (Du et al., 2020). Application of chemical fertilizer significantly improved Fonio yield in The Gambia (Sonko et al., 2022). Similar trends were reported by a crop modeling study, in which improved soil fertility management is crucial to reduce climate change-induced yield gaps (Raes et al., 2021). However, no studies assessing the contribution of fertilizer use to mitigation pillar in the Gambian context were available.

Conservation agriculture (CA) is practiced in semi-arid areas of West Africa, including in The Gambia, to enhance the productivity of the inherently poor fertility soils and combating soil degradation (Bayala et al., 2012; Partey et al., 2018; Thiombiano et al., 2022). CA is based on concomitant application of three principles: (a) minimum soil disturbance (through minimum or no tillage); (b) maintenance of a permanent soil cover (through cover cropping or mulching); and (c) diversified profitable crop rotation (Giller et al., 2015). No studies were available to enable the assessment the contribution of CA to CSA pillars in the Gambian context. In West Africa, empirical evidence shows that CA contributes to the productivity and adaptation pillars of CSA by improving soil structure and water retention, soil organic matter, soil fertility replenishment and reducing soil erosion (Bayala et al., 2012; Partey et al., 2018). In addition, CA-based systems can significantly improve soil health (Araya et al., 2021). The positive impacts on soil quality and fertility, and soil water conservation could result in increased farm productivity and income (Bayala et al., 2012; Araya et al., 2021). Legume intercropping significantly increases crop yield and income, even though the magnitude of the benefits depends significantly on socio-ecological contexts; it reduces the probability of low yields even under critical weather stress during the growing season (Himmelstein et al., 2017; Nyagumbo et al., 2020; Abdul Rahman et al., 2021; Mupangwa et al., 2021). A synthesis of 7-years on-farm experiments across five countries in Eastern and Southern Africa showed that maize-legume intercropping and rotation under CA had the highest maize yield advantages as well as the most stable maize yields compared to the conventional practices (Mupangwa et al., 2021). In addition, maize–legume intercropping can significantly reduce the risk of crop yield and financial losses, and represents a viable risk management option for smallholder farmers in sub-humid and semi-arid areas of West Africa (Abdul Rahman et al., 2021).

The first continent-wide meta-analysis of CA experiments in sub-Saharan Africa confirmed the positive effects of CA practices on soil and water conservation (Corbeels et al., 2020). However, effects on crop yields are too small to significantly improve food security of smallholders (Corbeels et al., 2020). Compared with conventional practices, CA slightly increased yields, with yield benefits stronger under the combined application of all three CA principles, in drier conditions and when herbicides were applied (Corbeels et al., 2020). A recent meta-analysis which evaluates the impacts of selected CSA practices widely implemented in Africa—green manure, conservation tillage, and crop residue retention— showed, however, that the practices significantly increase yield and soil organic carbon, although no significant change was evident in soil total nitrogen (Kichamu-Wachira et al., 2021). The main conditions for CA performance relative to conventional tillage involve use of rotations, low rainfall conditions, medium textured loam and well drained soils (Nyagumbo et al., 2020). Nevertheless, CA remains effective in mitigating the negative impacts of heat stress and rainfall variability, and provides climate resilience benefits to cropping systems (Komarek et al., 2021). Indeed, mulching enhances the stability and resilience of cropping systems with either no-tillage or conventional tillage under both high and low rainfall conditions (Mhlanga et al., 2021), thus, contributing to cropping system resilience. By improving soil physical properties and plant nutrient uptake, mulching was shown to increase groundnut yield in various locations in The Gambia (Ashrif and Thornton, 1965). Mulch application has positive effects on soil and water conservation, with soil and water loss decreasing with increasing mulch application rate (Li et al., 2021). In addition to improving soil carbon stocks and organic matter content (Bai et al., 2019; Kichamu-Wachira et al., 2021), CA has potentials in reducing GHG emissions attributed to plowing (FAO et al., 2018; Partey et al., 2018). Recent global as well as Africa-focused meta-analyses showed that cover crops and conservation tillage are effective at increasing soil organic carbon content, with the effects more pronounced in areas with relatively warmer climates or lower nitrogen fertilizer inputs (Bai et al., 2019; Kichamu-Wachira et al., 2021).

In Eastern and Southern Africa, where CA promotion has been strong and sustained, adoption rate was low and dis-adoption rate was high, because of physical, human, informational, and financial resource constrains (Giller et al., 2015; Lee and Gambiza, 2022). These generic smallholder farmers' constraints are also prevalent in West Africa as well as in The Gambia and could limit the upscaling of CA (Thiombiano et al., 2022).

Soil and water conservation practices

Several practices and techniques are commonly used by smallholder farmers in semi-arid areas of West Africa to prevent and reverse land degradation, improve infertility and increase land productivity, while increasing water retention in the soil (Zougmore et al., 2014). These include contour bunds or farming, Zaï and half-moon techniques (Zougmore et al., 2014; Partey et al., 2018). Although Zaï was mentioned as an adaptation option after the first stage (Figure 1), the scoping search was unable to find any publications on Zaï from The Gambia (Supplementary material 4). Two studies provided the evidence base to assess the contribution of contour bunds or farming to the CSA pillars (Wright et al., 1991; Doumbia et al., 2009). The water management options identified included the System of Rice Intensification (SRI) (Ceesay et al., 2006; Ceesay, 2011) and irrigation (Webb, 1991; Ceesay et al., 2006; Raes et al., 2021; Redicker et al., 2022), with empirical evidence from The Gambia.

Stone bund and contour/tie ridges have become popular among West African farmers for reducing erosion, conserving run-off water and improving water use efficiency on farmlands (Partey et al., 2018). In terms of productivity and adaptation, construction of contour bunds has been reported to prevent soil erosion, enable water to stay longer in farm areas and reduce loss of soil nutrients in The Gambia (Anderson, 2017). Under erratic rainfall distribution conditions, tied ridge cultivation significantly increased soil water reserves on modest slopes and is a viable tillage alternative for maize-based systems in semi-arid areas of The Gambia (Wright et al., 1991). By reducing soil erosion and runoff, and improving rainwater capture and conservation in soil, tied ridge cultivation significantly increased maize yields and soil organic carbon in The Gambia (Doumbia et al., 2009). In semi-arid areas of Mali, application of contour bounds increases maize and millet grain production, retains soil water and reduces erosion rate, resulting in farm productivity improvement (Birhanu et al., 2020). As a micro-catchment system, tie/contour ridges can serve as climate-smart rain water harvesting techniques during water limiting conditions (Partey et al., 2018). Combining contour ridging with integrated soil fertility management approaches synergistically increases crop productivity (Partey et al., 2018; Birhanu et al., 2020).

The use of stone bunds built along fields' contour lines, micro water-harvesting, and soil restoration not only increased yield in years of good rainfall but also reduced yield variability during droughts (Zougmore et al., 2014; Partey et al., 2018). Under water-limiting conditions, stone bunds are efficient techniques in improving soil water content through run-off control (Zougmore et al., 2014). By slowing down run-off, stone bunds also induce sedimentation of fine waterborne particles of soil and manure, resulting in a build-up of a layer of sediments rich in nutrients (Zougmore et al., 2014). Under erratic rainfall conditions, stone bunds contribute to conserving more soil moisture thereby helping to alleviate water stress during dry spells (Zougmore et al., 2014). By reducing the impacts of flood and drought extremes on farmers' fields, stone bunds enhance the adaptation of cropping systems to climate change and variability and as such represent a climate-smart approach (Partey et al., 2018). The effectiveness of the stone bunds is reinforced by combining with organic fertilizers (Zougmoré et al., 2011; Zougmore et al., 2014). In semi-arid areas of Burkina Faso, combining manure or compost with soil and water conservation techniques significantly increased sorghum grain yield compared to mineral fertilizer application (Zougmoré et al., 2011). Integrating soil and water conservation techniques with application of compost resulted in increased financial gains under adequate rainfall conditions (Zougmoré et al., 2011).

Zaï and half-moons are traditional integrated soil and water management practices developed from indigenous knowledge systems to combat land degradation and improve soil productivity of previously abandoned bared soils through biophysical and biological processes (Lahmar et al., 2012; Zougmore et al., 2014). It is a soil rehabilitation system that concentrates run-off water and organic matter in small pits (Zougmore et al., 2014). By contributing effectively to rehabilitate previously abandoned and degraded bare lands and substantially increasing crop productivity, zaï and half-moon practices improve smallholder farmers resilience to climate variability (Zougmore et al., 2014; Partey et al., 2018). In northern Ghana, adoption of *Zai* technology leads to significant gains in consumption expenditure, consumption expenditure per capita, and household income (Ehiakpor et al., 2019).

However, the expansion of Zaï and stone bunds can be constrained by their physically demanding and intensive labor requirements (Schuler et al., 2016; Etongo et al., 2018). In subsistence-oriented farming context in the semi-arid areas of West Africa, where no other alternatives are available, Zaï can be an option to reverse severe land degradation and improve households' livelihood and food security (Ndah et al., 2014; Schuler et al., 2016).

There is substantial evidence, including in The Gambia, that the System of Rice Intensification (SRI), an agroecological crop management system consisting of altering crop, soil, water, and nutrient management practices contributes to the CSA pillars (Ceesay et al., 2006; Thakur et al., 2016; Thakur and Uphoff, 2017; Graf and Oya, 2021). SRI increases crop productivity with lesser inputs and enhances cropping resilience to biotic and abiotic stresses (Ceesay et al., 2006; Ceesay, 2011; Thakur et al., 2016; Thakur and Uphoff, 2017; Graf and Oya, 2021). When locally adapted, SRI increases yield and profitability in West African rice farming, including in both poor and resource-endowed farmers farms (Graf and Oya, 2021). Indeed, compared to conventional practices for irrigated rice production, SRI enhances water productivity and reduces substantially water use (Thakur et al., 2016; Thakur and Uphoff, 2017). In addition, SRI practices create both larger, healthier root systems that make rice plants more resistant to abiotic and biotic stresses and more conducive environments for beneficial soil biota (Ceesay et al., 2006; Ceesay, 2011; Thakur et al., 2016; Thakur and Uphoff, 2017). SRI field experiments conducted in The Gambia showed a significant crop yield increase without higher application of inorganic fertilizer and with less requirement for water (Ceesay et al., 2006; Ceesay, 2011). Water productivity also increased greatly (Ceesay, 2011). In addition, production cost analysis showed that SRI production was economically cost-effective, with more than 95% increase in net return per ha compared to farmers' practices (Ceesay, 2011). There are also evidence that SRI practices enhanced nutrient uptake due to greater root growth and activity, and improved the nutritional content and quality of produced grain (Thakur et al., 2020). In addition to enabling farmers to increase crop productivity with less inputs and reducing exposure to both abiotic and biotic stresses, SRI also reduces net emissions of greenhouse gases, especially methane emissions from rice fields (Thakur and Uphoff, 2017; Hasanah et al., 2019). Rice fields managed with SRI practices can serve as a sink rather than a source for CH4 (Hasanah et al., 2019).

In a changing climatic and economic context, the development of irrigation is considered necessary to stabilize and increase yields and reap higher returns from farm inputs and technological investments (Manka, 2014; Fisher et al., 2015). In addition, the development of irrigation enables farmers flexibility in planting dates, choice of crop types and varieties, and number of growing seasons (Fisher et al., 2015). While only 6% of total cultivated area in Sub-Saharan Africa is currently irrigated, introduction of irrigation into rainfed cropping systems will be critical to future agricultural production (Fisher et al., 2015; Partey et al., 2018). Improved water harvesting and retention and irrigation systems are fundamental for increasing production and addressing the increasing irregularity of rainfall patterns (FAO et al., 2018; Partey et al., 2018).

Investments in developments of drip irrigation to improve water availability on farmlands can be seen as a climate-smart option, especially for high value vegetable crops in The Gambia (Manka, 2014; Partey et al., 2018). Promoted by international development assistance, historical investments in irrigation schemes in The Gambia had increased farm productivity, household income, food consumption, expenditure and investment in farm, and improved household food security income (Webb, 1991; Redicker et al., 2022). Irrigated agriculture created avenues for asset and capital accumulation at both household and national scales (Webb, 1991; Carney, 1998). There is evidence that drip irrigation systems are cost-effective options to increase crop yield and household income, thus contributing to poverty reduction and food security in the Sudano-Sahel zones of West Africa (Woltering et al., 2011; Wanvoeke et al., 2016; Partey et al., 2018).

However, most of the Gambia irrigation schemes failed to sustain their impacts on the long-term because of technical and institutional barriers (Webb, 1991; Carney, 2008; Mutambara et al., 2016; Redicker et al., 2022). For most irrigation schemes, there was insufficient maintenance, coupled with the poorly designed canal structures and drainage systems (Webb, 1991; Mutambara et al., 2016). The lack of long-term perspectives and institutional support led to a total failure of many of the irrigation schemes in The Gambia (Carney, 2008; Redicker et al., 2022). High initial cost and labor are key barriers to adoption of tidal irrigation systems while high cost of installation and maintenance is a key barrier limiting widespread adoption of drip irrigation systems in rice-based production systems (FAO et al., 2018). In addition to wetlands degradation (Carney, 2008), another maladaptive outcome of Gambia irrigation projects was land dispossession. In The Gambia irrigation schemes, land dispossession reproduced women's lack of independent land rights or reduced them, with deleterious consequences for their control over household income (Levien, 2017).

Agroforestry practices

The scoping search of evidence revealed one paper on the outcomes of farmer managed natural regeneration (FMNR) (Stoate and Jarju, 2008) and two on alley farming (Danso and Morgan, 1993a,b). In West Africa, agroforestry technologies are achieving tremendous impacts for adaptation, mitigation and improved food security (Bayala et al., 2014; Mbow et al., 2014; Partey et al., 2018). Adoption of farmer managed natural regeneration (FMNR) is particularly widespread in the arid and semi-arid areas of West Africa and considered as an important step to improving agricultural productivity, buffering climate risks and contributing to climate change mitigation (Bayala et al., 2014; Mbow et al., 2014; Partey et al., 2018).

By improving soil fertility through increased of soil organic matter, nutrient cycling and biological nitrogen fixation by leguminous trees, agroforestry technologies contribute to crop productivity improvement (Bayala et al., 2014; Mbow et al., 2014; Kuyah et al., 2019; Muchane et al., 2020). Alley farming trials in The Gambia showed that the application of cassia prunings plus recommended inorganic fertilizer significantly improved maize yield and grain quality in semi-arid areas of The Gambia (Danso and Morgan, 1993a). Beneficial effects of prunings may become more evident with repeated application. Incorporating prunings into the soil before crops are planted might reduce nutrient losses to volatilization as P, K and organic matter content declined less where prunings were applied to the maize crops (Danso and Morgan, 1993a). However, rice grain yield and quality did not increase when rice was alley cropped with cassia in semi-arid areas in The Gambia: there was no benefit in terms of rice grain yield and grain quality from addition of prunings or prunings and inorganic fertilizer (Danso and Morgan, 1993b).

A multi-country assessment study across the West African drylands indicated that keeping, protecting and managing trees on farmlands has significant positive impacts on the livelihoods of the rural poor (Binam et al., 2015; Weston et al., 2015). For instance, continuous practice of FMNR by a community of 1,000 households could increase income by US$ 72,000 per year (Binam et al., 2015). There is also evidence of a significant increase in household dietary diversity a result of FMNR (Binam et al., 2015). FMNR can act as an important safety-net by providing cash income, caloric intake, and crops supplements (Weston et al., 2015; Binam et al., 2017). In West African drylands, FMNR has been shown to improve rural livelihoods beyond agricultural and income benefits (Binam et al., 2015, 2017; Weston et al., 2015).

Agroforestry technologies contribute to adaptation through improving soil structure and water infiltration, providing soil cover that reduces erosion and buffers the impacts of climate change (Bayala et al., 2014; Mbow et al., 2014; Kuyah et al., 2019; Muchane et al., 2020). By reducing runoff and soil loss, improving water infiltration rates and soil moisture content, increasing proportion of soil macroaggregates, and enhancing stability of soil structure, agroforestry systems can reduce soil erosion rates by 50% compared to crop monocultures (Kuyah et al., 2019; Muchane et al., 2020). Microclimatic improvement through agroforestry has positive effects on crop performance as trees can buffer against climatic extremes (Bayala et al., 2014; Mbow et al., 2014). Because agroforestry systems have more biomass than treeless cropping systems, they represent an important carbon sink apart from forests and long-term fallows in Africa (Bayala et al., 2014; Mbow et al., 2014). This illustrates the strong potential of agroforestry systems in Africa for providing multiple ecosystem services, including sequestering carbon and reducing other agriculture related GHG emissions while maintaining crop productivity (Mbow et al., 2014; Kuyah et al., 2019; Muchane et al., 2020).

Adaptation practices for livestock systems

Following the three-step inventory approach (Figure 1), three adaptation options were identified for livestock systems in The Gambia, which included switching to drought-tolerant animal species or breeds, feed supplementation, and stock/herd size reduction (Asaolu et al., 2010; Olaniyan, 2017). Five studies provide the evidence base for assessing the contributions of feed supplementation to the CSA pillars in The Gambia (Little et al., 1991a,b; Akinbamijo et al., 2003; Faye et al., 2003; Asaolu et al., 2010). There were no studies assessing the outcomes of other options.

In pastoral communities, empirical evidence suggests that economic benefits from adoption of improved livestock breeds are likely invested in the form of livestock rather than household assets, suggesting that livestock, as a form of savings, represent a better resilience measure (Ogada et al., 2020). In The Gambia, the most important objectives of keeping livestock across wealth status is savings and insurance (Bennison et al., 1997; Ejlertsen et al., 2012). Other important livestock production objectives included ceremonial/dowry purposes, income generation, manure, draft and transport (Bennison et al., 1997; Ejlertsen et al., 2012). Livestock portfolios play a significant role as an income and consumption buffering strategy during severe droughts (Acosta et al., 2021). Reducing stock or herd sizes as an adaptation measure can be effective in reducing mortality due to feed insecurity during drought periods (Gaughan et al., 2019).

Modification of feeding practices by introducing feed supplementation as an adaptation practice can improve production efficiency by promoting higher intake or compensating low feed consumption, decreasing heat stress, reducing feed insecurity during dry periods and reducing animal malnutrition and mortality (Rojas-Downing et al., 2017). Experimental evidence in The Gambia showed that feed supplementation significantly increased weight gain of goats during pregnancy and lactation, as well as milk production (Faye et al., 2003). Under village husbandry conditions in The Gambia, supplementation of N'Dama cows with groundnut cake during the dry season significantly increased quantities of milk offtake for human consumption and rates of growth of the suckling calves, and significantly decreased losses of maternal live weight (Little et al., 1991a). Cost-benefit analysis indicated that groundnut cake supplementation was economically attractive for adaptation to drought impacts in the Sudano-Sahelian zone of The Gambia (Little et al., 1991a). Combination of groundnut hay and moringa leaves in same ration significantly improved nitrogen intake and retention, as well as total digestible nutrients of West African Dwarf goats, resulting in improved performance (Asaolu et al., 2010). In addition, sesame cake and cottonseed supplementation significantly increased growth rate of young N'Dama bulls (Little et al., 1991b). Moreover, horticultural residues can represent a high quality feed resource in terms of feed conversion to animal products if harnessed judiciously especially for the peri-urban dairy sub sector in The Gambia (Akinbamijo et al., 2003).

Beyond The Gambia, feed supplementation with maize or legume silages can reduce methane emissions from livestock production systems (Gerber et al., 2013; Hristov et al., 2013). Addition of concentrate feeds to poor quality forages can decrease methane emissions and emission intensity in small ruminants (Gerber et al., 2013; Hristov et al., 2013).

Agro-climatic information and services

While climate information services in planning and managing climate risks (Anderson, 2017; Amuzu et al., 2018), there were no studies assessing the outcomes of climate information uses in The Gambia. In addition to CSV sites in Senegal, climate information use has been reported in all the regions of Senegal bordering The Gambia (Ouedraogo et al., 2018; Diouf et al., 2020). In CSV sites in Senegal, farmers estimated that their production has doubled with the use of climate information services (Diouf et al., 2020). In fact, the use of climate information has significantly improved the main crop (rice, maize, sorghum, millet, and groundnut) yields and farmers' agricultural income in southern Senegal (Diouf et al., 2020). In addition, the use of weather and climate information increases crop income by between 10 and 25% in Senegal (Chiputwa et al., 2022). In Northern Ghana, the use of climate information improved farmers' technical efficiency and crop yield (Djido et al., 2021a). The productivity increase enables famers to cover their food needs year-round, and also generate income to cover other needs and expenses of their households (Dayamba et al., 2018). The use of climate information helps farmers to decide on the types of crop and varieties to cultivate, to choose the appropriate management techniques, and to identify the appropriate timing for each farming practice (Ouedraogo et al., 2018). Climate information use can also increase the adoption of other CSA practices such as water conservation measures and cropping system diversification practices (Djido et al., 2021b). This helps farmers to reduce the risks of crop failure and improve crop productivity. Combining agro-advisory services with climate information services offers an additional benefit in term of improved climate risk management as it helps farmers to plan for their production and other livelihood activities well before the season starts (Dayamba et al., 2018). This is achieved through a better understanding, by farmers, of their local climate features, a joint analysis of their resources and their individual circumstances and early planning of their production activities (Dayamba et al., 2018). This combined approach has successfully been implemented in Senegal and Mali to manage climate risks and enable farmers to make strategic plans long before the season, based on their improved knowledge of local climate features (Dayamba et al., 2018). Indeed, about 97% of farmers involved in Senegal found the approach "very useful" in helping them reducing exposure to climate risks and increasing yield (Dayamba et al., 2018).

Microfinance and weather index-based insurance

Currently, no empirical studies have been conducted in The Gambia to assess the outcomes of microfinance and weather index-based insurance in relation to household resilience and adaptive capacity. Literature from West Africa region suggested that individual or group savings can provide a buffer for short-term needs, increasing a household's ability to cope with shocks (Greatrex et al., 2015). Group savings can represent a self-insurance mechanism for the community or targeted groups (Greatrex et al., 2015). A randomized field experiment in Senegal and Burkina Faso showed that female farmers were more likely to invest in savings and less likely to purchase agricultural insurance than male farmers (Delavallade et al., 2015). Insurance was more effective than savings, with higher average yields and better ability to manage food insecurity and shocks for insurance subscribers (Delavallade et al., 2015).

Micro-insurance, particularly weather index-based insurance, can strengthen smallholder farmers adaptive capacity by reducing financial risks from climatic events, but has not been widely implemented in Sub-Saharan Africa (Fisher et al., 2015; Greatrex et al., 2015; Di Marcantonio and Kayitakire, 2017).

Benefits of weather index-based insurance include farm productivity increase, informed production decision making, efficient use of farm inputs, protection of farmer assets while offering disaster relief, increase in income and savings, and investment or adoption of more profitable production technologies (Delavallade et al., 2015; Greatrex et al., 2015; Bertram-Huemmer and Kraehnert, 2018; Gebrekidan et al., 2019; Haile et al., 2020). In Senegal and Burkina Faso, index-based agricultural insurance had positive impacts on farmers' productivity, resilience, and welfare (Delavallade et al., 2015). Weather index-based insurance can be effective at increasing input spending and use, crop yields, and capacity to manage food insecurity and shocks (Delavallade et al., 2015; Haile et al., 2020). Index-Based Livestock Insurance (IBLI) can reduce livestock mortality risk by 25–40 in Northern Kenya (Chantarat et al., 2013). In addition, It reduces exposure to large shocks and mitigates significantly downside risks for many households (Jensen et al., 2016). In southern Ethiopia, IBLI coverage helped to increase household income and milk production during drought years (Matsuda et al., 2019). It also helps pastoral households to reduce herd offtake, thereby sustaining the household's economic growth (Gebrekidan et al., 2019). Weather index-based insurance can facilitate recovery from shock (Bertram-Huemmer and Kraehnert, 2018). IBLI indemnity payments have positive and economically large effects on herd size, have relieved households from credit constraints, and help herders avoid distress sales and slaughtering animals, thus smoothing their productive asset base (Bertram-Huemmer and Kraehnert, 2018). In pastoral communities in Northern Kenya, IBLI payment and the induced investment and risk-management decisions help reduce the probability of distress sales of livestock and the slaughter of livestock, helping poor households escape poverty traps (Noritomo and Takahashi, 2020).

Livelihood diversification

Diversification of livelihoods options can help spread risk, generate new sources of income, and can therefore be a key climate change adaptation strategy (Anderson, 2017; Rao et al., 2020). In The Gambia, the most widely adopted adaptation strategy was to seek alternative income generating activities when crops failed (Yaffa, 2013). Households that have diversified their livelihoods with non-farm activities were more successful in avoiding loss and damage from the 2011 drought in The Gambia (Van Der Geest and Warner, 2014). The new techniques learnt by women through ActionAid's agroecology projects in

The Gambia provide alternative livelihood options and the opportunity for women to feed their families even in the face of crop failure (Anderson, 2017).

In The Gambia, migration or aspirations to migrate is culturally grounded and practiced by both vulnerable and non-vulnerable households (van der Geest and Warner, 2015; Conrad Suso, 2020). Migration depletes the farms of its labor, but contributes to food security through remittances sent back enabling food purchase by household members left behind (Sonko et al., 2020).

Indeed, migration is an important livelihood diversification and risk management strategy for households, including climatic risks (Maharjan et al., 2020; Rao et al., 2020). Remittances sent back by migrants contribute to diversify household income with income sources less sensitive to climate impacts, spread risks, and insure against external stressors (Maharjan et al., 2020; Rao et al., 2020). A cross-country analysis involving 32 sub-Saharan African countries showed that receiving international remittances is positively associated with more household food security (Sulemana et al., 2019). However, the frequency of receiving remittances is more important, with households receiving remittances frequently less likely to be food insecure (Sulemana et al., 2019). In a post-2011 drought survey in the North Bank Region of The Gambia, Yaffa (2013) found that temporary migration of household members to gain access to food or money to buy food was important for one out of four households. In this case, migration reflected a failure to avoid loss and damage induced by the 2011 drought (Yaffa, 2013; Van Der Geest and Warner, 2014). Migration contributes to improve household adaptive capacity, though depending on the contexts and circumstances (Maharjan et al., 2020; Vinke et al., 2020). While migration can be an effective adaptation option for some groups under certain circumstances, it can increase vulnerability and reduce their adaptive capacity for others (Vinke et al., 2020; Singh et al., 2022). Men's out-migration increases women's work-burden and increases food insecurity in terms of self-production, which is however compensated by increased access to marketed food through remittance received (Pandey, 2019). Rural out-migrants to urban areas can be associated with being food insecure (Atiglo et al., 2020). While remittances generally have a positive impact on food security and household welfare (Adams, 2011; Ajaero et al., 2018; Sulemana et al., 2019), remittances can have negative effects on labor supply, education and economic growth (Adams, 2011; Sonko et al., 2020).

A recent feasibility assessment of migration across economic, social, institutional and technological dimensions showed that implementing migration as effective adaptation in Africa has low feasibility (Williams et al., 2021). With the increasingly formal and informal agreements and cooperation on forced return with migrant-receiving states, following the transition to democracy in The Gambia (Cham and Adam, 2021; Schapendonk, 2021), it is unlikely that migration would be considered as a viable and sustainable adaptation option.

Conclusions and recommendations

Identifying, mapping and assessing adaptation options provides the evidence base that would enable informed decision-making and effective adaptation planning. In this paper, the systematic approach for stocktaking developed and illustrated with the case of The Gambia, responded to the call for innovative methods for synthesizing the diverse and rapidly expanding adaptation literature (Berrang-Ford et al., 2021). The approach has enabled the identification of a number of adaptation options that could inform adaptation planning in agriculture and food systems in The Gambia. The approach has also enabled the synthesis of the evidence on the outcomes of the use of the options in The Gambia. The findings highlighted how the identified options can potentially contribute to improving productivity and building resilience to climate change impacts while reducing GHG emissions in agriculture and food systems. Beyond The Gambia, the approach can also be relevant for and replicated in other least developed countries that are involved in the NAP process.

The paucity of evidence from The Gambia and the highly contextual and differential impacts of the identified adaptation options underscore the importance of careful consideration of barriers and enablers when developing policy and interventions in order to sustainably increase productivity and income while building resilience to climate risks and reducing GHGs emissions (Thomas et al., 2021). Also, this paucity highlights key knowledge gaps that require further investigation. While many of the identified adaptation options were implemented in The Gambia, very few papers assessed their outcomes on CSA pillars or on other SDGs such as gender equity (Roy et al., 2022). In addition, the very limited research assessing adaptation outcomes are very old references, which might not reflect the current biophysical and socioeconomic circumstances of the country. The understanding of the synergies and trade-offs among the identified adaptation practices in relation to their contributions to the CSA pillars is unclear, limiting the ability to provide actionable recommendations. This lack of sufficient research on adaptation outcomes in The Gambia is consistent with the global adaptation research. A recent systematic global stocktake of adaptation responses across sectors and regions revealed an overall paucity of evidence, with a negligible evidence of risk reduction outcomes (Berrang-Ford et al., 2021; Scheelbeek et al., 2021).

Although there is a paucity of evidence of their contributions to CSA pillars, the identified adaptation options represent a strategic portfolio of options, from which specific options can be tested through participatory research action to generate evidence of their effectiveness in the Gambian context. In this line, the Climate-Smart Village (CSV) approach can be a particularly useful participatory research action approach to consider, as it has proven to be effective in generating evidence on the effectiveness of CSA technologies across Africa, Asia, and Latin

America (Aggarwal et al., 2018). As smallholder farmers often rely on a diversity adaptation practices, smart combinations of the identified options to enhance synergies and minimize trade-offs to strengthen farmer resilience can also be tested through the CSV. Furthermore, not all adaptation technologies will work for all farm types, as farm households are heterogenous in terms of their vulnerability to climatic and non-climatic stressors, and their differential capacity to engage in climate risk management and livelihood transformation (Hellin and Fisher, 2019; Segnon et al., 2021a). Failing to account for this heterogeneity in adaptation interventions could potentially lead to maladaptive outcomes (Hellin and Fisher, 2019; Segnon et al., 2021a). Farm and livelihoods typology, as part of the CSV approach, can enable the appropriate targeting and testing of adaptation options and ensure that adaptation interventions match with adaptation needs. This participatory process in generating evidence is also crucial to the NAP process, as it is one of the recommended steps.

In addition, engaging with key stakeholders is also key to identify the priority adaptation options to test and scale up given local context information, preferences and alignment with national and sectoral policies. Key stakeholders to be engaged will include technical experts, policy makers, researchers (university and national agricultural research systems), NGOs, farmer-based organizations, and agribusiness actors.

Author contributions

ACS and RBZ conceived and designed the study with inputs from ZA, RG, SM, and PFDS. ACS and RBZ developed the methodology with inputs from PH. ACS performed the literature searches and wrote the first draft with inputs from RBZ. ACS, RBZ, RG, ZA, TC, PH, SM, and PFDS interpreted the findings and critically revised the manuscript for important intellectual content. All authors read and approved the submitted version.

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Conflict of interest

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

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.834867/full#supplementary-material

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