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# How community seed banks contribute to climate-resilient seed systems: evidence from Ethiopia, Malawi, and Nepal

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Farmer-managed seed systems (FMSS) deliver the bulk of seeds used by smallholder farmers in many countries of the Global South. Community-based agrobiodiversity management is a participatory approach to strengthening FMSS from within, often undertaken in collaboration with scientists and breeders. Community seed banks (CSBs) are central to this approach. While well-managed CSBs are widely recognised for their potential to enhance seed and food security and support climate-change adaptation, research-based evidence remains limited. This study fills in this gap by analysing the functions of CSBs in FMSS, their contributions to climate-resilient seed systems and how this affects local seed security. The findings are based on a comparative, qualitative in-depth case study of 17 CSBs, covering five CSBs each in Ethiopia and Malawi, and seven CSBs in Nepal. Our study highlights how CSBs contribute to conserving crop diversity and making it available locally. We also show how some CSBs contribute to variety enhancement and/or development, providing collaborative platforms for plant breeders and farmers. Another important function is capacity building in seed management and farming methods. The CSBs have helped farmers adapt their agricultural production to climate change by providing quality seeds of climate-resilient crop varieties in time for planting, and through capacity building in suitable farming methods. The study demonstrates how these CSBs have contributed to local seed security. However, not all varieties are always available, amounts may vary, and there have been instances of genetic erosion. In most cases, seeds are widely distributed through farmer-to-farmer-exchange and trade. Nevertheless, challenges of scale are evident, as the number of CSBs are limited, the numbers of members and farmers served by the CSBs vary, and CSB growth strategies have had only limited success. We conclude that CSBs perform multiple functions and that their contributions to developing climate-resilient seed systems are significant but have thus far been confined to relatively small segments of farmers.

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## 1 Introduction

Seed embodies the genetic potential for crops to adapt to diverse and changing environments (Kumar et al., 2022; McCouch and Rieseberg, 2023). Adapting crop production to climate change using available crop diversity requires well-functioning *seed systems*. A seed system refers to the individuals, groups, organisations, activities, and institutions that together determine variety development and management, seed production, and seed dissemination (Almekinders and Louwaars, 1999; Louwaars and de Boef, 2012). A distinction is often made between formal and "informal" seed systems. The formal seed system, which involves developing, registering, producing, and marketing certified seeds of improved varieties through authorised sales outlets regulated through legislation, dominates in the Global North. In many countries in the Global South, particularly in Sub-Saharan Africa and parts of South Asia, however, most seeds used by smallholder farmers are sourced from farmer-managed seed systems (FMSS). These may be accompanied by strong and formalised social and cultural norms but are often referred to in the literature as "informal." FMSS demonstrate valuable characteristics and are well adapted to local conditions and preferences, particularly in remote areas (Almekinders et al., 1994; Almekinders et al., 2021).

FMSS may be strengthened by drawing on competence and capacities from the formal seed system. *Integrated seed-sector development* is one approach to building such linkages, through a pluralistic approach to seed-sector development (Louwaars and de Boef, 2012). As efforts to strengthen FMSS from within, community-managed seed systems and community seed banks (CSBs) have developed in many countries of the Global South, both as farmer-led and integrated approaches. The Sixth Assessment Report of the UN Intergovernmental Panel on Climate Change (IPCC) highlighted community-based adaptation programmes as feasible and effective, explicitly mentioning CSBs as an example of a successful approach (IPCC, 2022). CSBs encompass a wide diversity of initiatives, which can broadly be defined as "informal or formal local institutions whose core function is to maintain seeds collectively" (Development Fund, 2011). Documented cases show that well-managed CSBs make substantial contributions to seed security and climate-change adaptation (Vernooy et al., 2017; Maharjan and Maharjan, 2018; Andersen, 2019a, 2019b; Porcuna-Ferrer et al., 2020; Andersen et al., 2022; Meixner Vásquez and Andersen, 2023). However, due to the limited number of cases and different foci of research, research-based evidence is still limited.

With this article we aim to help fill this gap by analysing the pathways through which CSBs contribute to seed security and resilience in Ethiopia, Malawi, and Nepal. To address these pathways, we start out by exploring our first research question: (1) what are the functions of CSBs in FMSS, and how are these functions performed? On this basis, we analyse our two core research questions: (2) what are the contributions of CSBs to climate-resilient seed systems? (3) How do such contributions affect local seed security?

## 2 Conceptual framework

To answer our first research question on the functions of CSBs in FMSS and how these functions are performed, we take the interdependent functions of seed systems as our point of departure: All seed-systems have a basic set of interdependent functions: (1) variety development and management; (2) seed production; and (3) seed dissemination (see Box 1).

We use these three core functions of seed systems to structure our analysis of the functions performed by CSBs (see Figure 1). The performance of these systems is influenced by various political, economic and biophysical factors, but this study is limited to the core functions.

BOX 1 The three interdependent functions of seed systems.

1. **Variety development and management:** Breeding crop varieties and selecting, storing, and producing seeds is the basis for all seed systems. In the formal seed System, there is a clear distinction between conservation of genetic resources and plant breeding. In FMSS, however, such a distinction does not exist. Here farmers continuously develop and manage varieties and populations from season to season by selecting, saving, exchanging, and using farm-saved seeds. Louafi et al. (2021) refer to this process as "crop diversity management," while Westengen et al. (2023) identify "variety development and management" as a shared function across both formal and FMSS.
2. **Seed production:** Seed production occurs through multiple approaches involving different types and classes as well as various actors. It includes on-farm production and seed saving by farmers, centrally organised production by private, public, and semi-public entities, and locally coordinated efforts facilitated by community-based Organisations such as seed-producer cooperatives and OBs.
3. **Seed dissemination:** Seed dissemination occurs through both market and non- market channels. On-farm seeds produced by farmers may be reused, exchanged, sold, or freely shared within families and communities, provided this is permitted by national legislation. Centrally produced seed by companies or public institutions is typically distributed through commercial outlets. Community-based seed producers disseminate seeds through seed loan Systems (by CBs) or direct sales to local users (e.g., by seed producer cooperatives).

*Based on van Etten et al. (2017); Christinck et al. (2018); Louafi et al. (2021); Westengen et al. (2023).*

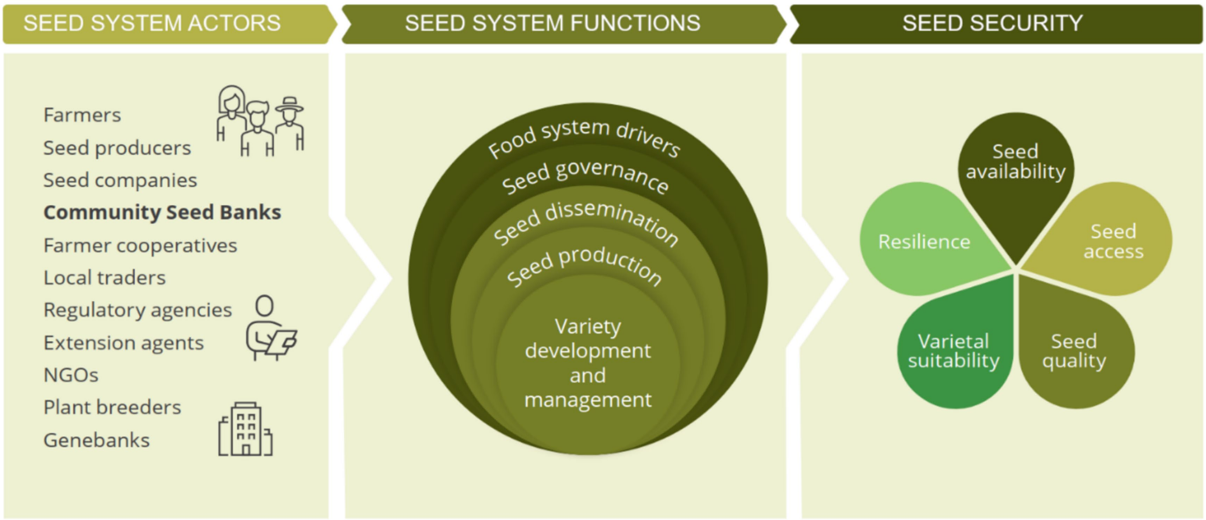


FIGURE 1
A conceptual framework for assessing CSBs contribution to climate resilience and seed security. Adapted from Mulesa et al. (2024), based on Westengen et al. (2023).

The performance of seed systems can be assessed by means of their *seed security* outcomes, which we take as our points of departure for answering the second and the third research questions on the contributions of CSBs to climate-resilient seed systems and local seed security. FAO (2016) defines seed security as a situation when "men and women within the household have sufficient access to adequate quantities of good quality seeds and planting materials of preferred crop varieties at all times in both good and bad cropping seasons."

A well-functioning seed system delivers seed security in terms of seed availability, seed access, seed quality, varietal suitability, and resilience. *Seed availability* is deemed adequate when there are enough quantities of preferred seeds to meet farmers' needs within reasonable proximity and in time for the local planting seasons (FAO, 2016; Sperling, 2008). *Seed access* refers to the ability of farmers to save and use farm-saved seeds or to acquire seeds in exchange for cash or through other means, such as loans, barter, social networks or exchanges among friends, neighbours and/or family members (FAO, 2015). CGIAR (Research Program on Roots, Tubers and Bananas) (2016) notes that access to seeds depends on: (1) delivery channels such as transport and distance; (2) affordability: whether farmers can buy seeds at the prices offered; and (3) seed information, i.e., how farmers learn about how and where to obtain quality seeds, as well as information on the varieties at hand, their qualities, the seed quality and price, which is of great importance to seed security (McGuire and Sperling, 2011; McGuire and Sperling, 2013). *Seed quality* refers to the seed's physical, genetic, and physiological properties. It is a technical parameter that includes various attributes such as germination, moisture content, physical purity, and – for some crops – varietal purity (FAO, 2015) and has a direct and important impact on crop performance and yield. Var*ietal suitability* refers to the ability of farmers to access seeds of crop varieties that meet their needs and preferences, such as yield, storability, high income potential, disease and pest resistance as well as for nutritional, culinary and cultural purposes (FAO, 2015).

Varietal suitability has become a central dimension of seed security in the face of climate change, as farmers in many areas need to switch to other crops and varieties to accommodate their production to the effects of climate change (IPCC, 2022). *Resilience* refers to the seed system's ability to resist, adapt to, and recover from shocks and stresses that threaten household seed security, such as the effects of climate change, by offering seed of a diversity of crops and varieties which are robust to such shocks and stresses. According to FAO (2015), a farmer is defined as *resilient* in terms of seed security if she/he can withstand the impacts caused by a significant stress, so that pre-existing levels of seed security are maintained or quickly recovered. The seed security dimensions of varietal suitability and resilience are closely interrelated and constitute our points of departure when exploring our second research question of how CSBs contribute to climate-resilient seed systems.

We analyse how CSBs affect climate resilience and seed security through variety development and management, seed production and seed dissemination, as illustrated by the three inner circles of the seed system functions in Figure 1.

## 3 Methods

This paper is based on comparative, qualitative case studies of 17 CSBs from three countries: five CSBs each in Ethiopia and Malawi, and seven CSBs in Nepal. It is one of several studies from the research project *Pathways to food security, poverty alleviation and livelihoods through the implementation of farmers' rights to crop genetic diversity (DIVERSIFARM)* (see acknowledgements for further information). The fieldwork was conducted in 2022 by three DIVERSIFARM-teams, all co-authors of this paper.

Case studies make it possible to explore the complexity of a given phenomenon and its multiple dimensions, perspectives, and causal relations (Yin, 2018). The case countries for the DIVERSIFARM project were selected based on four criteria: (1) a least-developed country

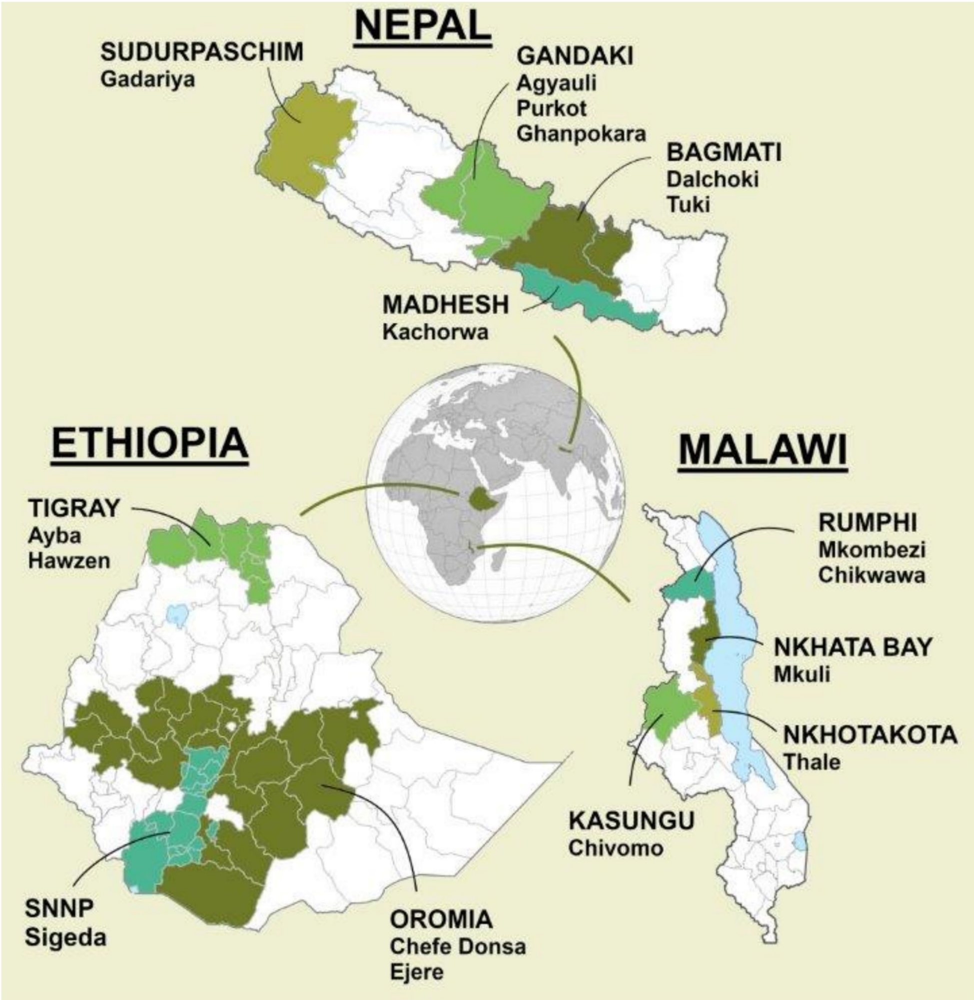


FIGURE 2
Map of Nepal, Ethiopia and Malawi, showing the locations of the CSBs studied.

affected by climate change; (2) experience with established and evolving CSB approaches, thereby allowing for the analysis of variation in practices and outcomes; and (3) had different policies and legislation regarding farmers' rights as they are addressed in the International Treaty on Plant Genetic Resources for Food and Agriculture, to identify their impacts on agrobiodiversity-based pathways to food security, poverty alleviation and livelihoods: this criterion is important for the analysis of success factors in other parts of the project, although it does not form part of the analysis presented in this article. Using these criteria, we selected *Nepal, Ethiopia*, *and Malawi* as case countries (see Figure 2).

We selected three CSBs in each country for in-depth case studies. To inform the case selection, we mapped CSBs in each of the three countries and developed a typology based on the results. In each country, we then selected the principal type of CSBs engaged in agrobiodiversity-related crop management. Within this category, we selected three CSBs per country that, on the basis of information gathered through the mapping process, were considered successful in terms of the contributions to seed security and climate resilience. Here we selected cases with different characteristics to ensure analytical diversity and relevance, capturing variation in agroecological zones, organisational structures, performance, and levels of external support. In addition, we collected data from other CSBs, including less successful and currently non-functioning cases, in order to capture a broader range of outcomes and to mitigate potential bias towards well-performing cases. The aim was therefore not to achieve national statistical representativeness, but rather to generate in-depth insights into how CSBs function under different conditions and to draw lessons from best practice. An overview of the community seed banks included in the study and their key characteristics is provided in Table 1 and their geographical location is illustrated in Figure 2.

For Malawi, we selected Mkombezi, Chikwawa and Mkuli CSBs as our focus. To control for our selection of CSBs, we also studied Thale CSB and Chivomo Community-based Field School; these were examples of different types of CSBs found specifically in Malawi engaged in promoting a few selected improved local varieties of one or few species without any further conservation activities. For Nepal, we selected Kachorwa, Agyauli and Ghanpokhara CSBs as our focus, but also collected data from Purkot CSB, another successful CSB from a different agroeconomic area in order to complement our information. To learn about the reasons for their comparative lack of success, we collected data from Dalchowki, Gadariya and Tuki CSBs—which had similar features but were perceived to be less successful or non-functioning. For Ethiopia, due to the outbreak of civil war in Tigray, the situation was challenging. The two CSBs we wished to include in our study from Tigray—Ayba

TABLE 1 Community seed banks studied and study participants.

| Community seed banks included in this study | | | | | Study participants | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Country / Name of the CSB | | Location | Total of members | Year of establishment | CSB members | | Non-members | | Key informants | | Total |
| | | | | | Female | Male | Female | Male | Female | Male | |
| **Malawi** | | | | | | | | | | | |
| **1** | **Mkombezi** | Rumphi district | 135 | 2010 | 16 | 13 | 3 | 3 | 0 | 6 | 41 |
| **2** | **Chikwawa** | Rumphi district | 120 | 2010 | 7 | 5 | 0 | 0 | 0 | 1 | 13 |
| **3** | **Mkuli** | Nkata-bay district | 18 | 2015 | 15 | 10 | 3 | 4 | 1 | 1 | 34 |
| **4** | Thale | Nkhotakota district | 140 | 2014 | 6 | 4 | 0 | 0 | 0 | 0 | 10 |
| **5** | Chivomo | Kasungu district | 35 | 2020 | 4 | 7 | 0 | 0 | 1 | 1 | 13 |
| **Sub-total of study participants in Malawi** | | | | | **48** | **39** | **6** | **7** | **2** | **9** | **111** |
| **Nepal** | | | | | | | | | | | |
| **6** | **Kachorwa** | Madhesh province | 450 | 2003 | 13 | 28 | 0 | 11 | 0 | 3 | 55 |
| **7** | **Agyauli** | Gandaki province | 953 | 2010 | 19 | 16 | 5 | 5 | 1 | 0 | 46 |
| **8** | Purkot | Gandaki province | 1,020 | 2010 | 2 | 7 | 0 | 0 | 0 | 0 | 9 |
| **9** | **Ghanpokhara** | Gandaki province | 150 | 2016 | 31 | 14 | 6 | 8 | 0 | 7 | 66 |
| **10** | Dalchowki | Bagmati province | 633 | 1994 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| **11** | Gadariya | Sudurpaschim province | 240 | 2007 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| **12** | Tuki | Bagmati province | 295 | 2004 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| **Sub-total of study participants in Nepal** | | | | | **68** | **67** | **11** | **24** | **1** | **10** | **181** |
| **Ethiopia** | | | | | | | | | | | |
| **13** | **Chefe Donsa** | Oromia region | 940 | 1998 | 10 | 15 | 5 | 10 | 0 | 5 | 45 |
| **14** | **Sigeda** | SNNP region | 94 | 2011 | 20 | 50 | 0 | 0 | 2 | 10 | 82 |
| **15** | **Ejere** | Oromia region | 600 | 1990 | 14 | 20 | 0 | 9 | 2 | 9 | 54 |
| **16** | Ayba | Tigray region | 133 | 2011 | 2 | 3 | 1 | 1 | 1 | 6 | 14 |
| **17** | Hawzen | Tigray region | 288 | 1996 | 2 | 5 | 1 | 0 | 0 | 4 | 12 |
| **Sub-total of study participants in Ethiopia** | | | | | **48** | **93** | **7** | **20** | **5** | **34** | **207** |
| **Total of study participants** | | | | | **164** | **199** | **24** | **51** | **8** | **53** | **499** |

The three CSBs in focus of our case studies in each country are shown in bold.





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TABLE 2 Community seed banks studied and the number of crop species and varieties conserved.

| No | Community seed bank | Number of species | Number of varieties |
|---|---|---|---|
| 1 | Mkombezi | 25 | 51 |
| 2 | Chikwawa | 17 | 48 |
| 3 | Mkuli | 6 | 20 |
| 4 | Thale | 1 | 2 |
| 5 | Chivomo | 2 | 4 |
| 6 | Kachorwa | 4 | 85 |
| 7 | Agyauli | 25 | 68 |
| 8 | Purkot | 43 | 136 |
| 9 | Ghanpokhara | 7 | 105 |
| 10 | Dalchowki | 4 | 149 |
| 11 | Gadariya | 1 | Around 25 |
| 12 | Tuki | Cereals and Vegetables | 104 |
| 13 | Chefe Donsa | 6 | 29 |
| 14 | Sigeda | 12 | 30 |
| 15 | Ejere | 15 | 142 |
| 16 | Ayba | 6 | 18 |
| 17 | Hawzen | 12 | 21 |

and Hawzen CSBs—were heavily affected by the war. They were both included in our study, but as additional cases exemplifying the roles of CSBs in conflict zones. Through consultants, we managed to collect data from one CSB in Oromia Region, Chefe Donsa CSB. We then added data from a previous study carried out in 2018 by the project leader that followed the same methodology and studied two CSBs with similar features but in different agroeconomic areas (Andersen, 2019a): Ejere and Sigeda CSBs. More information on the CSBs, the years of their establishment, the number of members and their location is provided in Table 1. Information on the number of species and varieties maintained in the CSBs is presented in Table 2, while more detailed information on supporting organisations is provided in Supplementary Table 1.

To gain a comprehensive understanding of CSB impacts, we employed a mixed qualitative methodological approach. This included:

- **Focus Group Discussions (FGDs)**: Conducted with both CSB members and non-members (i.e., local farmers who were not members but had observed the role and functions of the CSB in their community), these discussions gathered qualitative data on the operation and management of CSBs, as well as their contributions to seed security. In total, 42 FGDs (with 363 members and 75 non-members) were held, ensuring the inclusion of diverse voices by separating discussions by gender and representing various wealth and age groups, as well as different locations within the communities. We held four FGDs lasting around 2 h in each of the nine focus CSBs. The remaining FGDs were held in the two CSBs in Tigray, Ethiopia (Ayba, Hawzen), in the two additional CSBs in Malawi (Thale, Chivomo) and in one additional CSB in Nepal (Purkot).
- **In-Depth Semi-Structured Interviews (SSIs)**: For a deeper investigation of individual member farmer' experiences with the CSBs and to capture a wide range of perspectives on how CSBs have influenced their access to seeds and overall resilience to climate change, in-depth semi-structured interviews were held with 18 farmers (who also participated in the FGDs, and thus were included in the number of FGD informants above). These interviews were conducted on their farms, providing the opportunity to understand their contexts in more depth and to observe potential impact. An average of two farm visits were made for each of the nine core cases.
- **Key Informant Interviews (KIIs)**: For further data on the broader impacts and operational dynamics of the CSBs, interviews were conducted with 61 key informants: local authorities, representatives from extension services, and personnel from NGOs involved in facilitating, supporting, or observing CSB operations, members of the CSB management committees, member farmers of the CSBs, as well as non-member farmers from areas surrounding the CSBs.
- **Document Analyses**: Relevant documents regarding the CSBs were reviewed to triangulate findings from FGDs and interviews.

Altogether 499 informants (40% female, 60% male) from Nepal, Ethiopia, and Malawi were consulted, as detailed in Table 1.

All interviews were conducted after having obtained prior informed consent from respondents. With participants assured of anonymity, all FGDs and most key informant interviews were conducted in English and were translated into local languages, either by independent translators or case-study team participants. Meetings were documented with detailed note-taking; in the case of Malawi these were also recorded, transcribed and translated. In each CSB, a debriefing workshop was held to present and discuss preliminary findings with the management committees and other interested respondents. These meetings helped to validate data, and in some cases provided additional information. In Malawi and Nepal, national-level seminars were organised with central stakeholders from national authorities and the NGO community to discuss findings and enable an arena for considering follow-up measures, with 32 participants in Malawi and 14 in Nepal.

The data were analysed for each CSB using NVivo software programme version 14, released in 2023. Data were grouped according to seed-system functions and seed-security outcomes. A structured coding framework was developed based on the research questions and analytical focus of the study. The framework consisted of six main codes derived from the project codebook, covering (1) climate change, (2) factors of success of CSBs, (3) food security, (4) gender, (5) livelihoods, and (6) seed systems. Each main code comprised multiple subcodes, with a total of 42 subcodes across the six thematic categories, capturing specific dimensions such as drought tolerance, seed exchange, access to genetic resources, participation in CSB activities, income generation, and management structures. The coding process was conducted systematically across all case studies using this predefined structure. To ensure consistency of interpretation, coding decisions were discussed within the research team throughout the analysis process. Where relevant, additional residual subcodes were used to capture data that did not fit the predefined categories. Following the NVivo coding, the coded material was extracted and organised into an Excel matrix, where responses were grouped by code and by case study. This enabled systematic comparison across cases and supported the identification of key patterns and themes emerging from the data. The analysis involved a thorough examination of the contributions made by each CSB towards enhancing seed security among member and non-member farmers in the context of climate change.

# 4 Analysis and results

## 4.1 Seed system functions of CSBs

To answer our first research question on the functions that CSBs have in FMSS and how these functions are performed, we analyse the core seed system functions of CSBs, as set out in our conceptual framework, based on our case studies.

### 4.1.1 Variety development and management

All the CSBs studied in the three countries performed central functions at the local level in preserving and promoting crop diversity at both the species and variety levels. The number of species and varieties maintained by each CSB at the time the case studies were conducted is presented in Table 2. In addition to facilitating the continuous use and management of diverse local crops and varieties, most CSBs served—to various degrees—as platforms for demand-driven crop improvement. These results indicate that CSBs can strengthen the capacity of FMSS to maintain crop diversity and enhance and develop preferred varieties.

Across all three countries, the CSBs aimed at addressing the risks linked to erratic rainfall patterns and the mounting, often related, challenges posed by pests and diseases. By maintaining crop diversity with an emphasis on climate robust crops and varieties, and enhancing such varieties through participatory variety selection, and by providing capacity building in climate-robust farming methods, CSBs contributed to reducing the vulnerability of crop production and minimising potential losses.

In Ethiopia and Nepal, some CSBs collaborated with the national gene banks in the *ex situ* conservation of crop genetic diversity by multiplying and selecting seeds and submitting seed accessions of agreed varieties to the respective national gene banks.

Unlike most studies highlighting the role of CSBs in preserving crop diversity, our assessment revealed that genetic erosion may occur also within CSBs. For example, at Chefe Donsa CSB in Ethiopia, certain local varieties of leguminous crops, including black lentils (*Lens culinaris*), yellow fenugreek (*Trigonella foenum-graecum*), and black chickpea (*Cicer arietinum*) were no longer available: they were abandoned because they were seen to be susceptible to disease. Also, certain grain varieties were not maintained as they had been previously at Chefe Donsa CSB.

Generally, all CSBs maintained multiple varieties esteemed for their distinct aroma, taste, nutrition, suitability as livestock feed, storability, resistance to pests and/or climate robustness. However, for many of these varieties there were challenges with low yields and other factors, such as lodging or long maturity periods. This is why participatory variety selection has been important for most CSBs in all three countries. Through such methods, preferred local varieties have been enhanced and developed to increase yields, reduce maturity periods and to meet other requirements (see Box 2).

### 4.1.2 Seed production

Seed production is a core activity of CSBs, and all the nine CSBs in focus of our study contributed substantially to local seed production. Whereas one of the CSBs in Malawi and one in Ethiopia managed to meet the seed demand of their members only partially, all other nine CSBs studied in the three countries were found to meet the seed demand of their members. However, after challenging seasons there could be some variation. The two CSBs in Tigray in Ethiopia were badly affected by the devastating civil war (2020–22), the oldest one (Hawzen) being bombed.

Two CSBs in Ethiopia and five in Nepal had expanded their operations to produce certified or "truthfully labelled" seeds for government agencies and companies and for sale directly from the CSBs, thus playing an important role in both formal and informal seed production. Like other formal seed producers, commercial seed production by CSBs generally adhered to standard seed quality assurance and certification processes, with farmers reporting few quality issues.

In Ethiopia, the Chefe Donsa CSB joined the prominent multipurpose Erer Farmers' Cooperative Union and commenced commercial seed production to cover its operational costs after external support stopped. This CSB produced quality-declared seeds for local marketing and certified seeds of tef, bread wheat, lentils, chickpea, and beans, serving as out-growers for the union. Ayba and Hawzen CSBs in Ethiopia's Tigray region also produced seeds for the Farmers' Union. Kachorwa, Agyauli and Purkot CSBs in Nepal produced substantial quantities of seeds for sale of improved varieties of rice.

**BOX 2 Experiences with participatory enhanced/improved local varieties.**

At Kachorwa CSB in Nepal, a collaborative effort between farmers and breeders led to the development of the Kachorwa-4 rice variety through participatory plant breeding, coordinated by LI-BIRD and the Nepal Agricultural Research Council (NARC). Farmers expressed their satisfaction with Kachorwa-4's higher yield, early maturity, and delightful taste, emphasising its economic value and preferred culinary characteristics.

In Ethiopia, CSB members were involved in participatory variety selection programmes to improve local varieties in collaboration with breeders and scientists, although the extent of their involvement varied across sites. For instance, in the Northern region of Tigray, members of Ayba CSB were involved in Mekelle University's participatory durum wheat breeding and selection project. As a result, two varieties — *Wehabit* and *Rigeat*—were successfully developed, registered, and nationally released. In Ethiopia's eastern central highlands, CSB members in Chefe Donsa and Ejere were involved in participatory selection programmes for improved tef and durum varieties and legumes organised by the Ethiopian NGO Ethio-Organic Seed Action (EOSA), partly in collaboration with plant breeders at the Ethiopian Institute of Agricultural Research.

In Malawi, however, the advancement of crop improvement through participatory plant breeding and variety selection was limited. This was primarily due to the small landholding sizes among member farmers, which prevented them from allocating land for experimentation—compounded by limited technical capacity. The lack of communal land for establishing experimental plots further hampered progress. However, at Mkombezi CSB, four early-maturing local maize varieties had been enhanced through participatory varietal selection and particularly *Kafuja* is now widely used beyond the local community.

*Sources: FGDs with CSB members.*

CSBs in Malawi produced seeds for members only. Informants in Malawi reported that the quality of seeds obtained from CSBs was superior to the seeds they used to save before joining the CSBs and to those acquired from their social networks and local markets.

In all countries studied, farmers highlighted various factors contributing to improved seed quality, including training, improved storage facilities, and the role of seed quality control committees. These committees, typically composed of members of the CSBs, play a key role in monitoring seed quality throughout the production cycle. During the growing season, committee members often conduct field visits and provide technical advice to farmers to support good seed production practices. Upon return of seeds to the CSBs, they assess seed quality, including checks for moisture content, pest and disease damage, and compliance with locally defined quality standards. However, the capacity of CBSs in quality seed production varied significantly within and between countries, depending on infrastructure, technical expertise, and organisational performance.

### 4.1.3 Seed dissemination

The CSBs included in this study disseminated seeds of diverse crops and varieties to farmers. As indicated above, they disseminated seeds to their members, and some disseminated seeds of improved varieties more broadly, through commercial sales. The nine CSBs in focus of our case studies played a significant role in local seed dissemination. The other CSBs studied as part of this project disseminated seeds to varying degrees.

In Ethiopia and Malawi, CSB members received a fixed quantity of seeds each year based on their contribution or shareholdings and were expected to return the same quantity and quality of seeds of these varieties, with interest, to the CSBs, typically after the harvest. These interest rates varied, from 20% in Ethiopia, to 50% in Malawi. Notably, in Malawi, some CSBs had introduced a differentiated membership structure where associate members paid double the annual fee compared to regular members to gain equal access to seed loans. In Nepal, the system was purely monetary, where both members and non-members could buy seeds at the same price or in some cases at different prices but without major differences. Most CSBs studied in Nepal received start-up capital from their facilitating organisation to establish a seed fund. From this fund they purchased seeds produced by their members or other associated groups and sold the seeds for a higher price than they were purchased. This system enabled the seed fund to grow: the CSB could buy more seeds each year, allowing more farmers to participate in seed production and income generation through these activities, and to reach out to more farmers with more seeds. It also enabled the CSBs to earn income to cover administration, technical and other costs. Several CSBs in Nepal also distributed small quantities of seeds in the form of diversity kits, particularly of local varieties of vegetables, to poor and disadvantaged CSB members for free and to non-members at an affordable price.

Farmers in Nepal reported that seed production and marketing using revolving funds had contributed significantly to the expansion of seed stocks and the variety of the portfolio distributed by CSBs. Thus, the system contributed to seed security, and for many CSBs, to increased membership. However, CSB members were also aware of the necessity of limiting membership numbers to align with available resources and capacities.

In addition to the dissemination through the seed revolving schemes, as indicated above, some CSBs engaged in seed sales to non-members. These CSBs sold seeds of improved varieties that they produced as out-growers for farmer unions, local governments and agricultural extension offices, NGOs, as well as for designated nodal or model farmers who distributed them further.

Similarly, in the Tigray region in Ethiopia, CSBs engaged in selling the seeds they produced as well as those acquired from trusted sources. These seeds were sold directly to farmers, NGOs involved in seed aid initiatives, local agricultural extension offices responsible for government seed distribution, and to model farmers selected to distribute seeds to their fellow farmers. By contrast, CSBs in Malawi had not obtained the cooperative status necessary for selling seeds and other agricultural products.

The CSBs in all three countries organised diversity fairs occasionally, either seasonally or annually. These events served as important platforms for CSBs to distribute seeds and facilitate farmers' exchange of seeds and related knowledge.

CSBs have played a vital role in seed relief efforts during natural and man-made disasters in Nepal and Ethiopia. In Nepal, CSBs distributed locally adapted seeds from their stocks to neighbouring villages and districts affected by the 2015 earthquake and during the COVID-19 restrictions. In Tigray, Ethiopia, CSBs were instrumental in seed distribution during COVID-19 and the 2020–2022 civil war. CSBs distributed their own seeds and seeds obtained from individual farmers and local markets with the assistance of NGOs, to tackle the urgent seed needs of affected farmers in the region.

## 4.2 Seed security outcomes

Based on the analysis of the seed system functions of CSBs above, we now embark on answering our core research questions on the contributions of CSBs to climate-resilient seed systems and local seed security. This is done by analysing the seed security outcomes of the studied CSBs, as set out in our conceptual framework above, while recognising that the form and relative strength of CSB contributions differ across seed security dimensions and contexts.

### 4.2.1 Availability

Informants at all sites reported that the CSBs offered timely supplies of seeds for the planting season, but there were different experiences with the quantities of preferred seeds available, indicating that while basic seed needs were generally met, the volume and diversity of seeds could still be insufficient in some cases. For example, one of the best-performing CSBs in Ethiopia, Chefe Donsa, stocked more than 130 tons of seeds of different crops and varieties, including improved varieties, for dissemination in the 2021/2022 planting season, whereas Malawi's best performing CSB, Mkombezi, had 3.5 tons of seeds available at the time of our survey. Nevertheless, Mkombezi CSB had managed to provide its members with sufficient quantities of seeds of the preferred varieties. In contrast, Chefe Donsa CSB aimed to sell seeds of improved and registered varieties on a larger scale, shifting some of its focus from local to commercial varieties and from seed security to income generation, following the withdrawal of external funding. Such differences in orientation across cases may partly reflect variation in national policy environments shaping incentives for commercialization and engagement with formal seed systems.

In Nepal, informants noted that the availability of several varieties of important vegetables had improved since the CSBs were established. In Agyauli CSB, members reported having access to 12 previously unavailable varieties of vegetables. Members of Kachorwa CSB noted that among the benefits of accessing seeds from the CSB was the sizable portfolio of local varieties of rice. Ghanpokhara CSB members cited the revival of local varieties of foxtail millets as a particular achievement. In Ethiopia, members from Chefe Donsa CSB said that crop varieties such as durum wheat, bread wheat and tef were normally available in the CSB, whereas pulses and spices were limited. CSB members in the Tigray region were generally satisfied with the varieties available at local CSBs.

Regarding the volumes of seeds available from the CSBs, opinion was divided. Members of Mkombezi and Chikwawa CSBs in Malawi reported that the quantities of local varieties received, especially local varieties of maize, were sufficient for the areas allocated for food production on their farms. In contrast, in Mkuli, a Malawian CSB that had developed largely without external support, and in most sites in Ethiopia (except Ejere and Chefe Donsa CSBs), informants opined that the quantities shared through the CSBs, though important, were insufficient.

At Kachorwa CSB in Nepal, non-members expressed concern about the limited amounts of seeds of finger millet and sponge gourd. In Agyauli CSB, members noted that there were always enough rice varieties to meet their needs, but that the quantities of seeds of some crops like vegetables was limited.

One favourable point mentioned by all CSB members in Malawi was that they used the CSBs to store their own saved seeds. As documented in Andersen et al. (2022), they emphasised that this stopped them consuming their own seeds during food shortages, thus contributing to seed availability.

### 4.2.2 Access

Generally, CSB members had good access to the seeds that were available from the CSBs. Distances were short, transport was not a problem, the seeds were affordable for members, and they had sufficient information about the varieties at hand and the seed quality. Other farmers in the communities and surrounding areas could, in most cases, access seeds indirectly – or through sales outlets in the cases where CSBs offered seeds for sale.

**Transport and distance**: Informants in all three countries (except for Mkuli CSB in Malawi) gave positive feedback about the location of the CSBs, noting that they were situated centrally in the communities. Mkuli CSB was located outside a community centre but close enough for all members to have sufficient access to seeds in the planting season.

**Affordability**: Most informants in Malawi and Ethiopia saw the seed loan scheme as a unique opportunity for member farmers to access seeds and mentioned it as a main benefit of the CSBs. In Mkombezi, Chikwawa and Thale CSBs in Malawi, members had to pay an annual membership fee to access seeds from the CSBs, to cover CSB costs, at a level decided by the members. The willingness to pay this fee was high, as the gains granted in return—access to high-quality seeds of a wide portfolio of crops and varieties, capacity building and other services helping to improve their productivity—were considered substantial. Nevertheless, it could sometimes be difficult to pay the fee. Female members of Mkombezi CSB reported that access to seeds would sometimes be limited due to their inability to afford the annual membership fee. However, they would be re-admitted to the seed loan scheme as soon as they managed to pay.

Most members of the CSBs in Malawi and Ethiopia held that female and male members had equal access to CSB seeds, and that seed loans were available to all members, regardless of gender. This assessment is based on qualitative accounts and should therefore be interpreted with caution. Some male farmers from Mkuli and Mkombezi explained that more equitable access to planting material among members had been the result of gender training offered in the CSBs, which aimed to promote awareness of gender inclusion and participation in CSB activities. However, no systematic quantitative data were available on the volumes requested and received by women and men, or on the scale of seed loans and return rates disaggregated by gender. As such, the findings should be interpreted as indicative rather than conclusive.

According to the bylaws of the CSBs assessed in Malawi and Ethiopia, non-members could not borrow seeds directly from the CSB. Thus, many farmers in the surrounding communities wished to become members. This was a challenge, as many CSBs had reached their administrative capacity and were unable to accommodate further growth in membership and activities. Thus, they usually allowed new members only if old members left. Informants nevertheless explained that the CSBs, together with their members, had developed various ways of providing non-members with access to seeds, including through seed and food fairs. Except for one site in Malawi, non-members in Malawi and Ethiopia reported that they could access seeds through participating in such arenas. In addition, some non-members in Malawi indicated that they had improved their access to seeds through the satellite groups established by the Mkombezi and Chikwawa CSBs. In Tigray, some non-members reported that they could access CSB seeds by signing contracts. In contrast, in Mkuli CSB in Malawi, non-members expressed disappointment at not having access to CSB seeds: the capacity of the CSB was too limited, even for its own members. Nevertheless, Mkuli CSB offers an instructive example of a community seed bank established in a highly remote area, which, despite receiving external support only briefly at the outset, has continued to operate successfully within its limits.

In the case of Nepal, members and non-members alike reported having better access to seeds, as CSBs offered seeds at affordable prices for both groups. Farmers explained that, although they had to pay for seeds, CSB seeds were cheaper and of better quality than those obtained elsewhere. In all CSBs in Nepal, prices differed according to the types of varieties, but prices per variety were the same for members and non-members. This can explain why some farmers said they had no desire to become members, as they had the same access to seeds as members.

**Information**: Respondents from all three countries explained that CSB members could participate in agriculture-related meetings, training events and exchange visits provided by the NGOs that facilitated the CSB operations and by local extension services. Members emphasised that these activities enabled them to learn about good quality seeds. Generally, they were well informed about the seeds available from their CSBs. Informants mentioned that women, because they could not always attend activities, benefitted less from the trainings offered in the CSBs and therefore had less access to seed information and capacity building in the use of agricultural technologies. As male farmers explained, women have other household activities, such as childcare, and could not always attend or participate fully in meetings. Women members in Ejere CSB in Ethiopia, on the other hand, explained that capacity building had been decisive to their self-esteem and empowerment. Non-members did not have access to information at the same level, as some activities and services of the CSBs were exclusive to members. This was a clear disadvantage for non-members. However, CSBs engaged in the commercial sales of seeds informed the wider community about their offers.

This indicates that while access to seeds may be relatively equitable at the formal level, differences in access to information and participation in training activities affect how women and men benefit from CSB services in practice.

### 4.2.3 Seed quality

CSB members and non-members in the three countries asserted that the seeds they obtained from the CSBs were of "good quality," primarily based on their own experiences with seed performance and reliability. While seed quality is commonly defined in technical terms—such as germination rate, moisture content, and varietal purity (FAO, 2015)—the findings from this study indicate that farmers' assessments are often grounded in experiential criteria, including observed performance in the field and trust in the seed source. This suggests that seed quality should be understood as both a technical and a socially embedded concept. However, farmers did not always provide details of the quality features they appreciated the most.

Regarding germination, CSB informants from Kachorwa in Nepal, Mkombezi and Chikwawa in Malawi and the Tigray region in Ethiopia asserted that, according to their experience, seeds from CSBs had a high germination rate.

Members of Mkombezi and Chikwawa CSBs in Malawi rated CSB seeds as "good" because the seeds were stored for only one season before planting. In contrast, they remarked that they had been offered seeds from agrodealers, which had been stored for more than one season and had a reduced germination rate. Generally, the respondents believed CSBs to be trustworthy institutions as they could observe seed performance directly in the field.

A contrasting situation was found in Chefe Donsa, where most members believed that the seeds produced by the CSB were of lower quality than those from private companies in terms of varietal purity. CSB members explained that this was because they lacked the access to expertise to maintain varietal purity. Such expertise was no longer available due to a lack of funds. This contrast further highlights the importance of distinguishing between experiential assessments of seed performance and technical parameters of seed quality, particularly where specific attributes such as varietal purity require specialised knowledge and support.

### 4.2.4 Varietal suitability

Farmers at all sites studied held that a main benefit of having access to CSBs was that they provided varieties that were robust to climate change (see Box 3).

The drought-resistant improved varieties of rice, *Sukkha 2* and *Sukkha 3*, were mentioned by farmers at Kachorwa CSB in Nepal as becoming increasingly popular, as these helped them cope with the effects of climate change. At Sigeda CSB in Ethiopia, farmers held that local varieties were far more drought-resistant than improved varieties; they highlighted *black barley* as a key contribution of the CSB. At Hawzen in Tigray, farmers stressed the importance of the local variety *Hanfets*, a mixture of barley and wheat, provided by the CSB. They explained that in times of drought, *Hanfets* did better than barley or wheat alone. In Mkombezi and Chikwawa CSBs in Malawi, local varieties of maize and bambara nuts were mentioned as helping members cope with drought. The CSBs were the main suppliers of these varieties, which would otherwise have disappeared.

Concerning varieties resistant to pests and diseases, few informants mentioned specific names, but most agreed that CSBs had been instrumental in providing local varieties that were less susceptible to these blights. Farmers considered CSBs to be central in providing them with early maturing varieties as well as drought-tolerant ones: these genetic traits were considered of utmost importance in view of the increased prevalence of droughts.

Although most members and non-members noted how CSBs had provided them with varietal options to meet their needs and preferences—in particular with climate-adaptive varieties—farmers in all the three study-countries wished to expand their access to further crops and varieties (see Box 4).

**BOX 3 Examples of how varieties from CSBS are adapted to climate change.**

Both members and non-members noted early maturation, drought tolerance, and resistance to common pests and diseases as the most valued genetic traits in crop varieties.

In Malawi, most members reported particular satisfaction with the early-maturing local maize variety, *Kafula*, which performs well during drought (see also Andersen et al., 2022; Meixner Vásquez and Andersen, 2023). The local groundnut variety *Chalimbana* was also appreciated for its adaptability.

In Nepal, improved varieties were especially valued for their early maturation. At Kachorwa CSB, farmers highlighted two rice varieties: the locally improved *Kachorwa* 4, praised for its early maturity, strong stem, drought tolerance, and good eating quality, and the improved *Hardinath*-l, valued for its suitability in irrigated uplands, low water requirements, and strong market demand. At Ghanpokhara CSB, informants preferred the local foxtail millet variety *Bariyo Kaguno* for its early matu rity, high yield, large grains, and good taste.

In Ethiopia's Tigray region, farmers reported a shift to improved varieties due to shortened growing seasons. At Ayba CSB, over 90% of the members cultivated the improved bread wheat variety *King Bird*, known for its early maturity and tolerance to both drought and waterlogging. At Hawzen CSB, members also reported switching to early-maturing improved varieties, particularly of bread wheat and grain legumes.

*Sources: FGDs with CSB members*

**BOX 4 Crops and varieties that farmers wished to grow if seeds were available.**

In Chefe Donsa, Ethiopia, farmers expressed interest in crop varieties for both food consumption and income generation. These included spices, such as white and black cumin, as well as oil crops - particularly *noug (niger seed)*, sunflower, and linseed.

In Tigray, Ethiopia, farmers at Ayba CSB reported the need for faba bean varieties resistant to waterlogging and fungal diseases, especially to the "chocolate spot." At Hawzen CSB, farmers emphasised the importance of improved access to grain legumes, which play a key role in local crop rotation systems. Farmers from both CSBs in Tigray expressed a strong demand for disease-resistant vegetable crops, including potatoes, carrots, and sweet potatoes, as well as Off-season maize, valued for both consumption and income generation.

In Nepal, Kachorwa CSB members emphasised the need for both improved and local rice varieties, such as *Sonamasuli* (improved) and the popular *Lalka Basmati* and *Kariya Kamodh* (local varieties). In Agyauli, Nepal, farmers expressed demand for traditional rice varieties like *Aanp Jhutte* alongside improved varieties such as *Swarna (also known* as *Sona MasulJ)*.

In Malawi, many communities expressed interest in greater access to traditional varieties of finger millet, sorghum, and bambara nuts.

*Sources: FGDs with CSB members.*

**BOX 5 A farmer in Tigray explains how the CSB contributes to resilience.**

*"Our region is characterised by prolonged dry spells, and the cultivation of traditional small grain cereals, such as wheat and barley, in June (the main planting season) often faces growth and yield challenges due to insufficient moisture availability during critical growth stages. To mitigate these challenges, the CSB provides farmers with access to seeds of various resilient grain legumes, including lentils, fenugreek, grass peas, and chickpeas. These legumes are well-suited for planting during the middle of the main rainy season, typically after mid-July. Chickpeas, in particular, present a flexible planting option, as they can also be sown towards the end Of August, capitalising on any residual moisture available from earlier rains".*

*Sources: Member farmer (male) from Hawzen CSB, Tigray, Ethiopia. FGD with male members.*

### 4.2.5 Resilience

Generally, all CSBs studied were found to make farming more resilient in terms of seed security. In Nepal, farmers reported having access to seeds of varieties that were more robust to the effects of climate change. In Malawi and Ethiopia, members reported that the CSBs had helped to make them more resilient as they could meet their planting needs for the next season even after a complete or partial crop failure caused by erratic weather conditions. Members reported that the seeds met their varietal needs and preferences related to the effects of climate change. Farmers in the Tigray region and Mkombezi said that CSBs not only guaranteed their access to seeds when crops failed but also provided them with varieties more likely to adapt to and resist shifting climatic conditions (see Box 5).

Our informants also reported on how CSBs performed in times of crisis. Farmers in the CSBs in Ethiopia's Tigray region reported that, during the 2020–2022 civil war and COVID-19 restrictions, the CSBs served as springboards for reaching out to local communities with local as well as improved varieties. Similarly, informants in Malawi reported that during COVID-19, the CSBs continued to operate (in line with government recommendations), and members gathered to work on diversity blocks, receive seed information, and access seeds in time for the planting seasons.

**BOX 6 A farmer in Nepal explains how the CSB helped farmers during crises.**

*"The demand for locally produced seed increased, mainly due to the lack of import and supply of hybrids to the local Agrovets due to movement restriction during the COV/D-19 pandemic. This CSB played an important role in meeting farmers' needs for seeds and seed security during the pandemic and the 2015 earthquake."*

*Sources: Member farmer (male) from Purkot CSB, Nepal. EGD with members.*

In Nepal, informants explained that although meetings and training offerings were disrupted during COVID-19, access to seeds remained feasible for farmers living close to CSBs. For instance, in Purkot CSB, informants stated that the CSB was the main seed source during the pandemic (see Box 6).

## 5 Discussion and conclusion

In this article, we have explored the seed system functions of CSBs in FMSS and, on this basis, how CSBs contribute to climate-resilient seed systems and local seed security. The analysis was based on case studies of 17 CSBs in Nepal, Ethiopia and Malawi, of which 9 were selected as the core cases. The remaining 8 CSBs were included in order to capture a broader range of outcomes and to mitigate potential bias towards well-performing cases, thereby providing in-depth insights into how CSBs function under different conditions.

As to our *first research question* on the functions of CSBs in FMSS and how these are performed, the CSBs in all three countries were found to perform important roles and have multiple functions in their local FMSS. They contributed decisively to the acquisition, conservation and management of crop genetic diversity in their communities and in several cases also—through collaboration with breeders/scientists—to participatory enhancement and/or improvement of local varieties. Another important function was local capacity building in seed selection and management, and in farming systems and methods.

All CSBs facilitated the dissemination of seeds through seed loan schemes and revolving seed funds for members. Similarly, Vernooy et al. (2014), Msaki et al. (2015) and Maharjan and Maharjan (2018) concluded that CSBs have enhanced the dissemination of seeds to poor farmers on a loan basis in the areas they are located. Furthermore, we found that seeds from CSBs were disseminated through local seed fairs and markets (via member farmers) and commercial channels at affordable prices for non-members. The latter represent an increasing trend which necessitates some discussion. Several CSBs in Nepal and Ethiopia engaged in the commercial sale of seeds of improved varieties either directly from the CSBs or through 'daughter' companies, thereby marketing substantial and increasing volumes of seeds. Similar trends have been confirmed in studies conducted in Nepal, India, Uganda, and Zimbabwe (Vernooy et al., 2022) and Nepal (Andersen, 2019b). From our case studies, we found that the trend can be explained in particular by the following factors: (1) High demand for affordable quality seeds at the time of planting among farmers in the relevant areas; (2) Successful capacity building that had taken place in the CSBs, training high quality seeds producers who were known and trusted for their skills in their communities; (3) Economic advantages for seed producers in producing seeds for CSBs or their 'daughter' companies; and, (4) Recommendations from facilitating organisations to develop a source of income for the CSBs that would enable long term operations after the end of projects (economic sustainability).

There is a potential trade-off in this trend. CSBs venture into the commercial sale of seeds of some few improved crop varieties to reach out to farmers beyond their own membership and earn the income required to continue operations. Thereby they switch their focus away from promoting crop diversity, which was the original motivation for establishing the CSBs. We found, however, that all CSBs engaged in commercial seed sale continued to maintain their diverse crop collections. Members considered this important to be prepared for future agriculture in times of climate change. However, we also noticed discussions in several CSBs as to how these collections could be maintained over time and whether there would be a need to reduce the number of accessions conserved. The findings indicate that commercialization does not in itself lead to genetic erosion. While the Chefe Donsa CSB in Ethiopia demonstrates how a stronger commercial focus can coincide with reduced attention to crop diversity, other CSBs—particularly in Nepal—combine commercial seed production with continued diversity management, and no instances of genetic erosion were observed in these cases. This suggests that the relationship between commercialization and genetic erosion could be shaped by context-specific conditions. Key mediating factors could include the availability of technical capacity for varietal maintenance, continued external support, and institutional arrangements within CSBs. Where such capacities are limited—as observed in Chefe Donsa—the risk of genetic erosion may increase. Commercialization should therefore be understood as a potential trade-off or conditional risk of genetic erosion. Nevertheless, in their emerging role as commercial outlets of seeds, CSBs and their 'daughter' companies have become significant contributors to local seed production and dissemination, as confirmed also by De Falcis et al. (2022), Adokorach et al. (2020) and Vernooy et al. (2020).

Thus, in answering our first research question, we conclude that the three core CSBs studied in each country contributed fundamentally to strengthening local FMSS. In addition, the CSBs among these that focus on the commercial sale of improved crop varieties contributed substantially to expanding formal seed systems locally. We also conclude that the remaining CSBs included in this project have contributed to varying degrees to strengthening local FMSS.

Regarding our *second research question* on the contributions of CSBs to climate-resilient seed systems, we conclude that the nine CSBs in focus of our study in all three countries play a vital role locally in adapting crops and agricultural methods to the effects of climate change. They offer access to a wide range of crops and varieties that are adapted and adaptable to the local environment. Many of these crops and varieties are particularly tolerant to climate-related stresses, some are early maturing, and most have good storing qualities, especially important over prolonged drought periods. Importantly, quality seeds of such varieties are provided in time for planting. The enhancement and improvement of local varieties also help to increase the yields of these varieties while maintaining properties such as drought tolerance and resilience to other environmental stresses, and early maturity and/or storage qualities. Capacity building in climate-robust farming methods is another important contribution of most CSBs.

Across the five seed security dimensions, the contributions of CSBs differ both in form and in relative strength. Given the qualitative nature of the empirical material, these differences are identified through comparative and interpretive analysis across cases and dimensions. Contributions are generally more direct and consistently strong with regard to seed availability, varietal suitability and resilience, where CSBs actively maintain diverse crop portfolios, provide seeds in time for planting seasons, and support the development and dissemination of locally adapted varieties. By contrast, contributions to seed access and seed quality tend to be more conditional, uneven or indirect, depending on factors such as membership structures, affordability, access to information and training, and the availability of technical expertise.

These differences are also evident across cases. For example, availability and varietal suitability are strongest in CSBs that maintain broad and actively managed crop portfolios and have effective dissemination mechanisms in place, whereas access remains more limited for non-members or where institutional and financial barriers persist. Similarly, contributions to seed quality depend on the presence of technical capacity and/or support for maintaining specific quality parameters such as varietal purity. Overall, this indicates that CSB contributions are multidimensional and context-dependent, with some functions being more decisive than others under specific conditions.

Concerning our *third research question* on how such contributions affect local seed security, we found clear evidence that these contributions have a positive impact, although their strength and form differ across seed security dimensions. The seed-security outcomes of the nine CSBs in focus of our study included, with varying strength across dimensions: (1) substantially increased local *availability* of seeds of a range of crops and varieties preferred by farmers – primarily local crops but increasingly in Nepal and Ethiopia improved local varieties or varieties from formal breeding programmes; (2) facilitated *access* to seeds of this diversity for both women and men CSB members that fully or partly covered their demand for preferred crops and varieties, and to some extent also for non-members (particularly in Nepal and Ethiopia); (3) the provision of *good quality seeds*; (4) improved var*ietal suitability* as based on farmers' criteria, and (5) strengthened *resilience* of agricultural production.

As stated above, we found—through gender separated focus group discussions—that women and men had roughly equal access to seeds in all the studied CSBs. This contrasts with the findings of Reisman (2017) in Telangana, India, and Nyantakyi-Frimpong (2019) in Northern Ghana. In these studies, cultural norms systematically excluded women from seed-bank decision-making, limiting their access to seeds. A core reason for the gender-balanced approach in the main CSBs we studied, as explained by our respondents, is that the CSB members had been exposed to training in gender issues. This confirms the major importance of such capacity building to promote equal access to seeds among women and men.

However, limitations of the seed loan schemes were noted in some CSBs. In Ethiopia and Malawi, there were two main challenges related to the implementation of such schemes: (1) quality issues, in that the returned seeds did not always meet quality standards; and (2) the pay-back system, in that farmers did not always return the agreed amounts of seeds. The consequences were reduced growth of seed stocks and the time-bound exclusion of members unable to comply with the terms and conditions of the seed loan schemes. As a result, in some of the CSBs we studied, there would not always be enough seeds of all preferred varieties.

Another limitation to the local effects of CSBs is their membership-based exclusivity, also discussed by Vansant et al. (2022). Members in Malawi and Ethiopia benefitted directly from the CSBs by receiving seeds, information and capacity building, whereas other farmers benefitted indirectly to the extent that they could access seeds and information from members or through seed fairs and local markets. Due to the challenges encountered of managing such large institutions, there was little scope for expanding the activities when these limits to growth were reached. Thus, many farmers who wanted to become members remained outside the CSBs. In both countries, central CSBs experimented with satellite CSBs to seek solutions. In Nepal, the borders between members and non-members were softer, as many CSBs offered seeds to members and non-members alike, shared information more widely and CSBs managed to grow considerably. However, these were CSBs engaged in the commercial sale of seeds and thus there are limitations in translating these models to other contexts.

We conclude that the core CSBs examined in this project fulfil multiple seed-system functions. They contribute substantially to local seed production, dissemination, and management. Several have also contributed, to some extent, to local variety development. Through these seed-system functions, together with related capacity building among CSB- members, they have significantly advanced climate-resilient seed systems and enhanced seed security at the local level. The remaining CSBs included in the project have likewise contributed to these outcomes, albeit to varying degrees. But problems of scale are evident: the numbers of CSBs are limited, the number of members and farmers served by the CSBs vary, and growth strategies have had limited success. Thus, the significant contributions of well-functioning CSBs to developing climate-resilient seed systems are confined to relatively small segments of farmers.

Here we have focused on how CSBs contribute to core seed-system functions and seed-security outcomes, with particular attention to the climate-change context. Seed systems and CSBs are also influenced by a range of political, legal, economic and biophysical factors that fall outside the scope of this paper. The DIVERSIFARM case study teams have collected and analysed substantial data on these factors, to be presented in forthcoming articles, with a focus on success factors as well as barriers, in order to indicate how CSBs may improve their performance, sustainability and outreach and the conditions for scaling-out the best models.

## Data availability statement

Anonymised data sets supporting the conclusions of this article will be made available by the corresponding author, without undue reservation.

## Author contributions

RA: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. VV: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. TM: Conceptualization, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. OW: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. DG: Investigation, Resources, Validation, Writing – review & editing. RW: Investigation, Resources, Validation, Writing – review & editing. FA: Investigation, Resources, Validation, Writing – review & editing. PS: Investigation, Resources, Validation, Writing – review & editing. YT: Investigation, Resources, Validation, Writing – review & editing. KA: Investigation, Resources, Validation, Writing – review & editing. TA: Investigation, Resources, Validation, Writing – review & editing.

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and improved livelihoods, success factors and relevance to other contexts, aimed at providing a basis for scaling out good models.

## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

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## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2026.1830059/full#supplementary-material

## References


Adokorach, J., Vernooy, R., and Kakeeto, R. (2020). *Scaling Community Seedbanks and Farmer Seed Enterprises in East and Southern Africa. Workshop Highlights, 2–4 October 2019*. Entebbe: The Alliance of Bioversity International and CIAT.

Almekinders, C. J. M., Hebinck, P., Marinus, W., Kiaka, R. D., and Waswa, W. W. (2021). Why farmers use so many different maize varieties in West Kenya. *Outlook Agric.* 50, 406–417. doi: 10.1177/00307270211054211

Almekinders, C. J. M., and Louwaars, N. P. (1999). *Farmers' Seed Production: New Approaches and Practices*. London: Intermediate Technology.

Almekinders, C. J. M., Louwaars, N. P., and de Bruijn, G. H. (1994). Local seed systems and their importance for an improved seed supply in developing countries. *Euphytica* 78, 207–216.

Andersen, R. (2019a). *The impact of the Development Fund's and EOSA'S Community-based Agrobiodiversity Programme in Ethiopia. Evaluation Report*. Lysaker: Fridtjof Nansen Institute.

Andersen, R. (2019b). *The impact of the Development Fund's and LI-BIRD'S Community-based Agrobiodiversity Programme in South-East Asia – with Emphasis on Nepal. Evaluation Report*. Lysaker: Fridtjof Nansen Institute.

Andersen, R., Meixner Vásquez, V., and Wynberg, R. (2022). *Improving Seed and Food Security in Malawi: The role of Community Seed banks* FNI Policy Brief 1/2022. Lysaker: Fridtjof Nansen Institute.

CGIAR (Research Program on Roots, Tubers and Bananas) (2016). *Multi-Stakeholder Framework for Intervening in RTB Seed Systems. RTB Working Paper No. 2016-1*. Lima: CGIAR.

Christinck, A., Rattunde, F., Mulinge, W., and Weltzien, E. (2018). "Identifying options for the development of sustainable seed systems: insights from Kenya and Mali," in *ZEF Working Paper Series No. 165*, eds. C. Borgemeister, J. Braun, M. Denich, T. Stellmacher and E. Youkhana (Bonn: Center for Development Research).

De Falcis, E., Gauchan, D., Nankya, R., Martinez Cotto, S., Jarvis, D. I., Lewis, L., et al. (2022). Strengthening the economic sustainability of community seed banks. A sustainable approach to enhance agrobiodiversity in the production systems in low-income countries. *Front. Sustain. Food Syst.* 6:803195. doi: 10.3389/fsufs.2022.803195.

Development Fund. (2011). *Banking for the Future: Saving, Security and Seeds*. Oslo: Development Fund.

FAO (2015). *Voluntary guide for national Seed Policy Formulation*. Rome: Food and Agriculture Organization of the United Nations.

FAO (2016). *Seed Security Assessment: A Practitioner's guide*. Rome: Food and Agriculture Organization of the United Nations.

IPCC (2022). *Climate change 2022: Impacts, Adaptation, and Vulnerability*. Cambridge: Cambridge University Press.

Kumar, S., Jacob, S. R., Mir, R. R., Vikas, V. K., Kulwal, P., Chandra, T., et al. (2022). Indian wheat genomics initiative for harnessing germplasm resources. *Front. Genet.* 13. doi: 10.3389/fgene.2022.834366

Louafi, S., Thomas, M., Berthet, E. T., Pélissier, F., Vaing, K., Jankowski, F., et al. (2021). Crop diversity management system commons. *Agronomy* 11:1893. doi: 10.3390/agronomy11091893

Louwaars, N. P., and de Boef, W. S. (2012). Integrated seed sector development in Africa. *J. Crop Improv.* 26, 39–59. doi: 10.1080/15427528.2011.611277

Maharjan, S., and Maharjan, K. (2018). Roles of community seed banks in climate adaptation in Nepal. *Dev. Pract.* 28, 292–302. doi: 10.1080/09614524.2018.1418838

McCouch, S. R., and Rieseberg, L. H. (2023). Harnessing crop diversity. *Proc. Natl. Acad. Sci.* 120:e2221410120. doi: 10.1073/pnas.2221410120

McGuire, S. J., and Sperling, L. (2011). The links between food security and seed security. *Dev. Pract.* 21, 493–508. doi: 10.1080/09614524.2011.562485

McGuire, S., and Sperling, L. (2013). Making seed systems more resilient to stress. *Glob. Environ. Chang.* 23, 644–653. doi: 10.1016/j.gloenvcha.2013.02.001

Meixner Vásquez, V., and Andersen, R. (2023). Community seed banks: Instruments for food security or unsustainable endeavour? A case study of Mkombezi Community Seed Bank in Malawi *Food Sec.* 15, 1087–1108. doi: 10.1007/s12571-023-01374-4

Msaki, M. M., Regnard, I., and Mwenda, M. (2015). Cereal banks or seed banks? *Dev. Country Stud.* 5, 18–26.

Mulesa, T. H., Otieno, G., Dalle, S. P., Mohamed, M. D., and Westengen, O. T. (2024). *Seeding Diversity*. Norway: Crop Trust and Norwegian University of Life Sciences.

Nyantakyi-Frimpong, H. (2019). Visualizing politics. *Geoforum* 105, 109–121. doi: 10.1016/j.geoforum.2019.05.014

Porcuna-Ferrer, A., Fiala, V., Freyer, B., van Etten, J., Vernooy, R., and Probst, L. (2020). Do community seed banks contribute to resilience? *Int. J. Agric. Sustain.* 18, 232–249. doi: 10.1080/14735903.2020.1747199

Reisman, E. (2017). Reframing expectations for village seed banks. *World Dev.* 98, 160–168. doi: 10.1016/j.worlddev.2017.04.024

Sperling, L. (2008). *When Disaster Strikes: A guide to Assessing Seed system Security*. Rome: CIAT.

van Etten, J., López Noriega, I., Fadda, C., and Thomas, E. (2017). "The contribution of seed systems to crop diversity," in *Mainstreaming Agrobiodiversity in Sustainable Food Systems*, ed. A. Bailey (Rome: Bioversity International), 80–101.

Vansant, E. C., Bezner Kerr, R., Sørensen, H., Phiri, I., and Westengen, O. T. (2022). Exchange and experimentation: community seed banks strengthen farmers' seed systems in Northern Malawi. *Int. J. Agric. Sustain*, 20, 1415–1436. doi: 10.1080/14735903.2022.2122254

Vernooy, R., Jai, R., Ahlawat, S. P., and Malik, S. K. (2020). *Community Seed banks as Seed Producers. Working Paper Series No. 2*. Lima: CGIAR.

Vernooy, R., Rana, J., Otieno, G., Mbozi, H., and Shrestha, P. (2022). Farmer-led seed production. *Seeds* 1, 164–180. doi: 10.3390/seeds1030015

Vernooy, R., Sthapit, B., Galluzzi, G., and Shrestha, P. (2014). The multiple functions of community seed banks. *Resources* 3, 636–656. doi: 10.3390/resources3040636

Vernooy, R., Sthapit, B., Otieno, G., Shrestha, P., and Gupta, A. (2017). The roles of community seed banks in climate change adaptation. *Dev. Pract.* 27, 316–327. doi: 10.1080/09614524.2017.1294653

Westengen, O. T., Dalle, S. P., and Mulesa, T. H. (2023). Navigating towards resilient and inclusive seed systems. *Proc. Natl. Acad. Sci. USA* 120:e2218777120. doi: 10.1073/pnas.2218777120

Yin, R. K. (2018). *Case Study Research and Applications: Design and Methods*. London: Sage.