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Comparing the contribution of formal and local seed systems to household seed security in eastern Zimbabwe

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Introduction: Interventions aimed at improving the seed security of smallholder farmers do not always yield positive results. Governments, donors, and other actors have neglected local seed systems as they are assumed to be incapable of addressing farmers' seed challenges. Instead, external actors use seed aid and formal seed provisioning outlets, such as agro-input dealers, to channel seed to farmers. This paper compares the "formal" seed systems, mainly comprising certified seed obtained from government and non-governmental organisations and agro-input dealers, with local seed systems that include farm-saved seed, local informal markets, and social networks.

Methods: A seed security assessment was used to determine the contributions of seed systems to household-level seed security. A stratified sample was conducted of 227 randomly selected smallholder farming households from the Chimanimani district, eastern Zimbabwe, complemented by group discussions and individual life histories.

Results: We show the superiority of local seed systems in ensuring greater access to affordable and timely seed at household level, in comparison to formal sources. Cluster analysis enabled determination of the seed security status of farming households, providing a more granular analysis beyond the standard seed security assessments that are applied to wider geographical locations. Farmers assessed the quality of locally sourced seed favourably when compared to seed obtained from formal sources.

Discussion: We show that local seed systems play a critical role in contributing to household seed security for resource-constrained households, and in supporting the use of diverse crop species. However, such systems have not been fully drawn upon by government and development agencies in seed security endeavours. More efforts are needed to understand how different seed systems interact in contributing to the seed security of smallholder farming households.

KEYWORDS

seed security, seed availability, seed access, seed quality, local seed system, formal seed system, seed aid

1. Introduction

Smallholder farmers in Southern Africa rely substantially on agriculture, both for their source of food and livelihood (Gollin, 2014). However, national policies and local interventions do not often address constraints that affect smallholders' production and seed systems (Louwaars et al., 2013; Visser, 2015). Access to adequate quality seed can be an important entry point for promoting productivity, food and nutrition security and resilience among smallholder farmers (Almekinders et al., 2019; Ruane et al., 2022). Many agricultural projects address seed insecurity through increasing the supply of certified seed of improved crop varieties (Sperling and McGuire, 2010; AGRA, 2014). Such interventions also include community seed production, emergency seed aid, and crop input subsidies, which comprise important agricultural responses used in the Global South to address seed insecurity and the high prevalence of food insecurity (Remington et al., 2002; Bengtsson, 2007).

Smallholder farmers source their seed from various avenues that can be broadly categorised as "formal", "informal" and an intermediate system that reflects a hybrid of the two. Own-saved seed, seed from local markets, and seed accessed via social networks constitute the informal seed system, herein after called "local seed systems," while agro-dealers and seed aid are part of the so-called formal seed systems (Louwaars and de Boef, 2012; Croft et al., 2017; Sperling et al., 2020). Large-scale seed aid is typically provided via the formal seed channels, while small-scale seed aid can be supplied from local markets and community seed banks. Formal seed systems are regulated by national governments which register new and improved varieties of seed whose quality is assured by a defined certification process (Sperling and Cooper, 2003; Louwaars and de Boef, 2012). The public and private sectors are key players in this system. Seed systems, also referred to as farmer-managed or traditional seed system (Almekinders and Louwaars, 2002), are not officially regulated, operates at individual and community level, and provides the bulk (60–100%) of seed for smallholder farmers (Louwaars and de Boef, 2012). The intermediate seed system refers to individual farmers and groups that produce and sell seed following a quality assurance scheme that is not managed by the formal systems (Kansiime and Mastenbroek, 2016; McGuire and Sperling, 2016; Mulesa et al., 2021).

Smallholder farmers participate in both formal and local seed systems to obtain the quantity and quality of seeds they need. The formal seed systems are typically used by farmers to access specific crop varieties primarily for the purposes of selling their produce to the market. In contrast, crop varieties from local seed systems are preferred by farmers for food preparation, culinary, taste and cultural needs, in addition to selling the produce. These are crucial factors that influence the decisions that farmers make about which seeds to source. Crop varieties sourced from local seed systems may also originate from different sources, including the formal seed system, as there are many linkages and interdependencies across these systems (Almekinders and Louwaars, 2002; Westengen et al., 2023).

The formal seed system in Zimbabwe includes a well-functioning seed industry with maize—the staple crop—the focus of breeding and seed sector efforts. Maize is also the main food crop obtained from the formal sector by smallholder farmers (CIAT et al., 2009; Mazvimavi et al., 2017). The local seed system supplies over 90% of the seed Zimbabwean farmers sow, especially sorghum, pearl millet, groundnuts, cowpeas, Bambara nuts, sugar beans and sweet potato (CIAT et al., 2009; Mujaju, 2010). The government, donors, and non-governmental organisations (NGOs) use a combination of seed interventions to assist farmers in recovering from climate-related and other emergencies (Brumel, 2004; Oxfam, 2016; Mujaju et al., 2017). Such initiatives aim to support drought relief, address climate variability, and improve food security and nutrition, among others. Yet questions remain about the extent to which they contribute to improving farmers' seed security, defined as having sufficient access to adequate quantities of good quality seed and planting materials of preferred crop varieties at all times (FAO, 2015a). The aim of this paper is to compare the role of formal and local seed systems in contributing to the seed security of smallholder farming households in eastern Zimbabwe.

Seed security assessments are used by research and development agencies to review the functioning of seed systems that farmers use, and to determine whether adequate seed of good quality is available (FAO, 2016; Dalle and Westengen, 2020). Although several studies have conducted seed security assessments (e.g., CIAT et al., 2009, 2010, 2011; Mazvimavi et al., 2017; Mulesa et al., 2021), these tend to focus on post-disaster relief and typical growing periods, and do not explicitly compare the extent to which formal and local seed systems contribute to seed security at household level. In particular, while such studies demonstrate the extent of seed used from local and formal sources, they do not systematically compare availability, access and quality dimensions at the individual farmer level, a gap that this paper seeks to address. The Integrated Seed Sector Development (ISSD) framework has gained momentum in recent years, aiming to develop a more pluralistic seed sector regime that recognises the contributions and development of both formal and local seed systems (Louwaars and de Boef, 2012). The ISSD also offers opportunities for the simultaneous development of various seed systems that provide for the diversity of demands related to different crops, farming systems, markets, and farmers (Louwaars et al., 2013). Although the ISSD framework has been useful in describing the benefits of both formal and local seed systems, it has not explicitly compared the influence of these systems on household-level seed security, a contribution to be made by this paper.

Seed security has multiple dimensions. This study goes beyond simple binary comparisons (e.g., percentage of seed supplied from one system), and instead explores how each system contributes to the seed security dimensions of availability, access and quality. It applies statistical analysis to cluster farmers in terms of their seed security profiles, and juxtaposes these analyses with vignettes of farmers' circumstances to illuminate the conditions affecting their seed security. The structure of the paper is as follows. Following a description of the methods used we review the concepts of seed security at household level. We then compare the seed security of farmers in terms of seed obtained from formal and local seed sources, and group farmers into seed security clusters. Lastly, we discuss these findings in relation to broader literature, concluding with recommendations for policy and action.

2. Materials and methods

2.1. Study sites

Chaseyama and Chikukwa wards, located in the Chimanimani district of eastern Zimbabwe (Figure 1), were selected as case study sites due to their different bio-physical characteristics and agricultural potential. Chaseyama is on the western side of the district and is characterised by low rainfall (300–450 mm *per annum*) with periodic, seasonal droughts and with predominantly shallow, sandy soils, derived from granite, that are inherently infertile. The area is mostly unsuitable for dry-land crop production. Chikukwa, on the other hand, located on the eastern part of the district, is characterised by

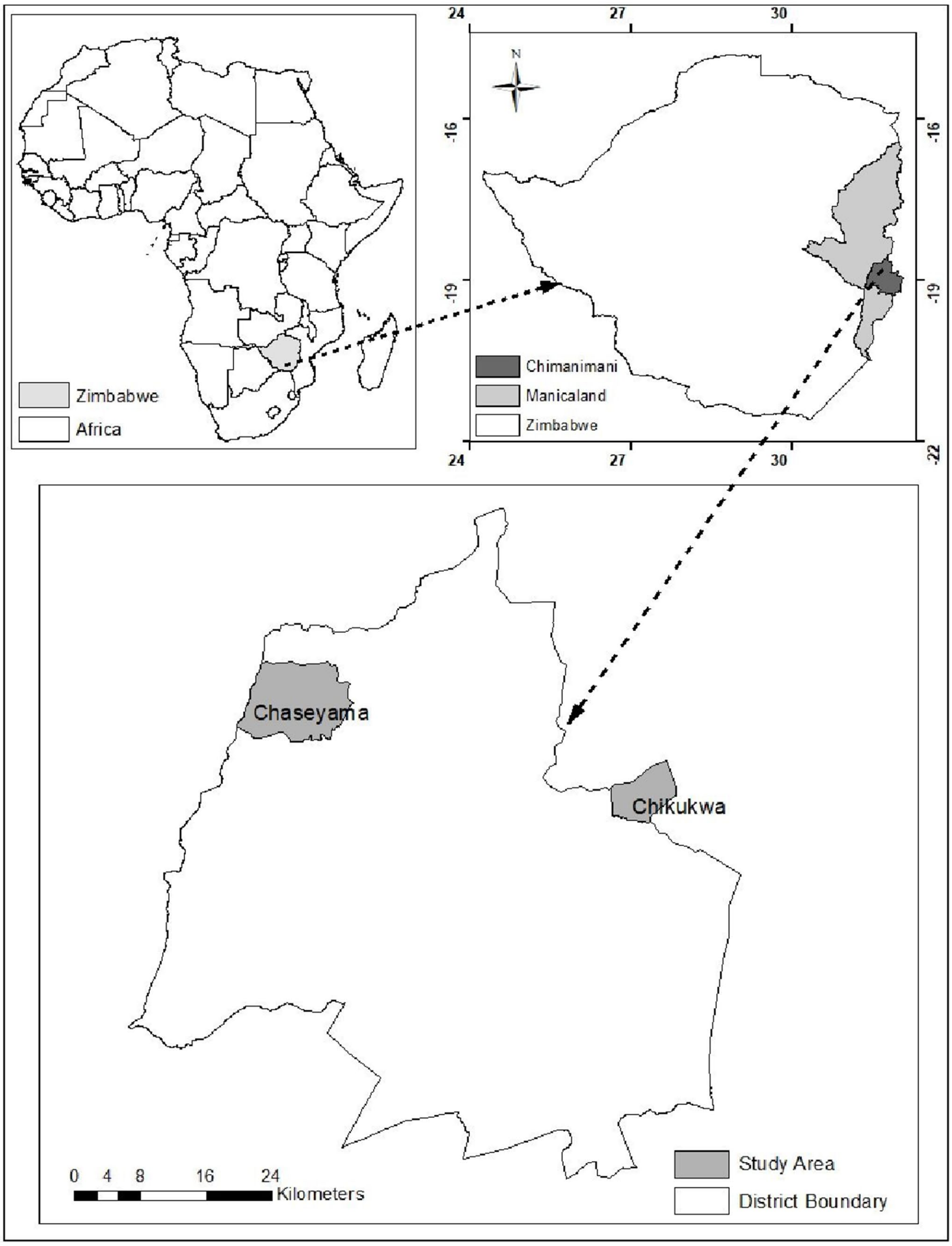

FIGURE 1
Map of: location of Chimanimani district in Zimbabwe where Chaseyama and Chikukwa wards are situated.

high rainfall of 1,000 mm *per annum* with much cooler temperatures. The area has deeply weathered red-clay soils that are highly suitable for diversified cropping and high-value crops such as coffee, tea, and potatoes (Mugandani et al., 2012; Oxfam-UNDP/GEF, 2015). Chikukwa is located in a very remote area, has a mountainous terrain not easy to navigate, and has few service centres like shops. Chaseyama, on the other hand, has a flat terrain transversed by major roads (from Mutare to Chimanimani and to Masvingo) and many service centres.

Farming communities in both areas have benefited from multiple seed assistance interventions such as seed aid, local seed production, seed fairs and seed banks. Seed aid includes seed directly supplied mostly by government programmes, through either the Presidential input support scheme, or via Command Agriculture (Pindiriri et al., 2021). The former targets smallholder farmers in communal areas with seed crops for household food security, while the latter targets large-scale farmers growing commercial crops such as maize, wheat, soya and sunflower, particularly in irrigation schemes. Local seed production is usually facilitated through contracts with seed companies or NGOs operating in communal areas. Seed fairs are supported by NGOs and seed companies, and aim to ensure that farmers access a diverse range of seed from local and external sources. Seed banks, mostly facilitated by NGOs, involve the significant participation of local farmer groups who aggregate a diverse range of crop varieties for storage, sharing and exchange.

2.2. Seed security concepts

Many scholars and development actors use seed security assessments as the basis of determining the extent of household seed insecurity and proposing appropriate responses (CIAT et al., 2012; FAO, 2016; Dalle and Westengen, 2020). The dimensions of household seed security include availability, access, varietal suitability, seed quality, and the resilience of the seed system (FAO, 2015a). According to Remington et al. (2002), seed availability means "having sufficient seed of desired crops within reasonable proximity (spatial availability) and in time for sowing (temporal availability)." It therefore refers to the farmer's supply of seed from all sources. These sources can include own-saved seed, social networks, local markets, the formal seed sector and aid sources (FAO, 2015a; McGuire and Sperling, 2016).

Access to seed is defined as the ability to acquire seed through exchange, loan, barter, or use of influence in social networks (Sperling et al., 2013; FAO, 2015a). Sperling et al. (2013) also highlight the importance of access to relevant information about seed properties and management as a critical but under-appreciated part of seed access. Differentiating access from availability is vital because the seed might be available within the community or market, but some farmers might not have the resources or the social influence to acquire it. Access consists of social access and economic access (FAO, 2015a). Social access refers to acquiring seed through a household's social network, while economic access means having the financial resources to acquire seed when needed.

Seed quality looks at the technical aspects of the seed, focusing on germination, physical purity, seed health and varietal purity (Walsh et al., 2014; FAO, 2015a). Seed germination requires tests to ascertain the percentage of seedlings that germinate from a given sample. Physical purity refers to seed that is clean and free from foreign material with no broken or immature grains. Seed health implies that the seed should be free from pests and diseases. Varietal suitability refers to seed with characteristics preferred by farmers (FAO, 2016). Shrestha (2020) further divides varietal suitability into adaptability to local agro-ecological conditions, and choice, which comprises the desired traits meeting farmers' production, food, cultural and market needs.

The resilience of a seed system is the extent to which seed security is affected by stresses and shocks (Lin, 2011; McGuire and Sperling, 2013; FAO, 2015a). McGuire and Sperling (2013), emphasise the idea of "maintaining the functions of the elements of a system, giving attention to the institutions, relationships and knowledges of local and formal systems." The FAO (2015a) argue that the resilience of a seed system can be measured by changes in the indicators of seed availability, access, and quality (i.e., the components of seed security). These indicators were used as the basis for determining the seed security of farming households in this study.

2.3. Study methods used

FAO's seed security assessment tools were adapted and used to assess the seed security status of Chimanimani farming households (FAO, 2015a,b). Methods included a survey conducted in 2017 with 227 randomly selected households, and an agro-input dealer survey at 12 shops. The household survey captured key seed security aspects such as availability, accessibility, quality, and adequacy. The agro-input dealer survey collected information related to commercial seed stocking and seed sales. These surveys were complemented by two focus group discussions with farming households from Chaseyama and Chikukwa, as well as 10 individual life histories of farming households that provided in-depth knowledge of farmers' characteristics, farming approaches, livelihoods, and information on how their use of different seed has shaped and contributed to seed security. The quantitative data were entered and analysed using SPSS software, while the qualitative data relied on thematic analysis. To validate and triangulate the information collected in 2017, literature and articles published before and after this period were analysed.

Indicators of seed security were grouped according to the FAO classification (FAO, 2015b) that considers availability, access, and quality (utilisation). Cluster analysis was done using SPSS to segregate households into groups based on their seed security characteristics. Specific variables were selected for the cluster analysis based on seed access, availability, and quality. For example, the seed availability component included seed proximity, timely provision, and seed presence at the level of the seed supplier. The seed access component included perceptions about seed affordability, the gender and age of the household head, and the number of times the household had received seed aid. The seed quality component included tests of germination and physical purity. Based on this initial variable selection, an algorithm was developed to determine the number and size of clusters under each domain of seed availability, access, and quality.

3. Results

3.1. Seed sources in Chimanimani district

The crops grown included maize, sorghum, pearl millet, groundnuts, Bambara groundnut, cowpeas, beans, pumpkins, and yam. Table 1 compares the seeds of these crops, grouped into formal sources (mostly government-provided assistance and agro-input dealers), and local sources (own seed, social networks, and local markets). The results reveal that, with the exception of maize, local sources dominated, accounting for at least 70% of the seed supply. Local sources were thus essential in supplying both the bulk and diversity of seed crops needed by these farming households. This finding corroborates other studies which show that local seed channels are the main sources of seed for small grains and legumes, providing over 80% of the seed grown in Zimbabwe (McGuire and Sperling, 2016; Mazvimavi et al., 2017). Maize, being at staple crop, was mostly sourced from government aid (subsidies), agro-input dealers and own seed. Sorghum was mostly sourced from own seed, seed aid (from NGOs) and social networks as the seed (open-pollinated) can easily be saved and re-used in the subsequent seasons. Besides maize, own sources provided both the highest diversity and highest quantities of seed across crops.

3.2. Seed availability by source

Figure 2 compares the timing of seed from different sources (see also Table 1). The local seed sources included local market and social networks, while formal sources comprised agro-dealers and seed aid.

TABLE 1 Comparison of seed supply from formal and local sources.

Crop	n	Seed source: 2016–2017 (%)					
		Local sources			Formal sources		Total all sources (kg)
		Own stock	Local market	Social network	Agro-dealer	Seed Aid	
Sorghum	87	67.3	1.9	13.3	0.0	17.4	470.0
Maize	197	15.7	1.6	2.4	32.1	48.2	3850.0
Groundnut	107	41.4	22.8	12.8	23.0	0.0	313.0
Bambara groundnut	95	82.3	1.2	9.0	7.5	0.0	207.7
Cowpeas	82	64.4	4.2	3.2	12.7	15.5	142.0
Pearl millet	28	65.5	22.6	7.9	0.0	4.0	88.5
Finger millet	49	89.6	5.5	2.2	0.0	2.7	91.0
Beans	91	56.0	20.5	15.3	8.2	0.0	856.5
Pumpkin	92	72.7	0.2	21.7	5.4	0.0	9.2
Yam	46	92.2	0.0	7.8	0.0	0.0	1545.0

Source: Field survey, 2017. "*n*" refers to the number of farmers interviewed.

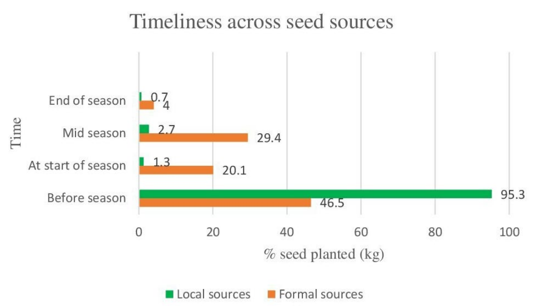

FIGURE 2
At what time was the seed available?

The results show that most of the seed from local sources was obtained before the planting season, compared to seed from formal sources, which was obtained after the season had commenced. These results suggest that there was a higher probability of farmers acquiring their seed from local seed sources in time for the planting season. Local markets and social networks provided a readily available source of seed for farmers, while there were delays in supplying seed on time from agro-dealers. Seed aid was provided at the middle or end of the planting season, which tended to be too late to be useful. Own seed was not included in the analysis as farmers have more control over its timing for planting needs. One farmer from Chikukwa described the value of his own seed plot for seed security, explaining that:

> "I never lack any seed as I have seed stored from the previous year that I replace with new seed that has been harvested. Had I lost seed due to poor germination, I would have had enough for replanting. I own a seed plot and food plot. For my maize seed, I observe isolation distance and time to prevent contamination. In early November before most farmers had planted their crops, I already had planted my seed plots. I have 2 acres for the seed plot. My best land (good soil and wetland) is used for seed production. The plot for food production is about 1 ha." (Christy, Life Case History Interview, Chikukwa, 2017).

The reliance of such farmers on own seed production ensures that they have adequate quantities of the required seed at the time of planting. The availability of seed in a timely manner is critical for smallholder farmers as most are reliant on rainfed agriculture, characterised by erratic and unpredictable rainfall that is further compounded by climate change effects. Although all farmers may not segregate their farming plots into seed and food crops, the presence of seed producers such as Christy contributes to wider seed availability for exchanges and sales.

The proximity of formal seed sources to farmers was compared to local seed sources. The results show that nearly all seed acquired from local sources was accessed within the village, while two- thirds of seed from formal sources was accessed within the village (Figure 3). Although both seed sources were found to be sufficiently close to farmers, the local seed sources provided the largest quantities of seed by volume. Seed obtained from far away districts was mostly from formal sources. As travelling to further locations has a financial cost and could be time consuming, access to seed from far locations may not be possible for all farmers. Local seed sources are thus the primary suppliers of most seed used by farmers, although there may be cases where they fail to supply the type of seed needed.

The data from agro-dealers serves as a useful illustration. Agro-dealers were not evenly spread across Chaseyama and Chikukwa but were in easy to reach central business centres along tarred roads. The mountainous terrain and unpaved roads in Chikukwa made the business centres less accessible than in Chaseyama. There were also fewer business centres in the more remote Chikukwa compared with Chaseyama. Famers who require certified seed were forced to commute to agro-dealers and seed company agents to obtain seed, even if it meant travelling to distant towns such as Mutare or Chipinge over 100 km away. Although there were similar numbers of farmers across Chaseyama and Chikukwa that accessed seed from agro-input dealers, the geographical location (i.e., terrain, infrastructure, and services available) of a community played an important role in shaping the nature of farmers' seed availability.

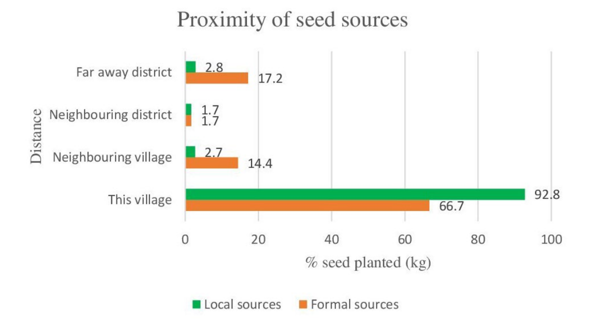

FIGURE 3
Where did you get the seed?

TABLE 2 Results of two-step cluster analysis of Chaseyama and Chikukwa households based on seed availability status for crops grown during the 2016–2017 season.

Variable	Cluster 1 (45%; *n* = 101)	Cluster 2 (36%; *n* = 81)	Cluster 3 (19%; *n* = 43)
Seed timeliness	On time (100%)	Late (100%)	On time (100%)
Seed proximity	Near (100%)	Far (57%)	Far (95%)
Seed adequacy	Yes (**57%**) No (43%)	Yes (22%) No (**78%**)	Yes (**63%**) No (37%)

Bold indicates the larger proportion of farmers. Predictor importance ranges from 1 (most important) to 0 (least important) predictor of the cluster. It thus has the most impact on determining the clusters (i.e., grouping of the households). The predictor importance output was generated from the SPSS two-step cluster analysis. Predictor Importance: timeliness = 1; proximity = 0.56; adequacy = 0.13.

3.3. Seed availability at household level

The temporal availability, spatial availability and sufficiency of seed (in terms of quantity) available from different sources have been identified as key elements for assessing seed availability (Remington et al., 2002; FAO, 2016). Based on three key cultivated crops, a cluster analysis was conducted using seed availability variables to group households with similar characteristics. Household-level seed availability was "on time" if all required seed across key crops was available in a timely manner (i.e., before or at the start of the planting season). If at least one of the key crops was only available late (i.e., mid-season or at the end of the season), the household was classified as "late." For the proximity variable, a household obtained a classification of "near" if all three major seed sources were obtained from their own village and/or neighbouring villages; "far" was when seed was further away for at least one of the three crops. For the adequacy variable, a household was classified as having "adequate" seed if they responded "yes" to the question of whether seeds were available from all their sources. If the household responded "no" to any of their seed sourced they were classified as "no"/inadequate. Table 2 illustrates the three distinct clusters of seed availability categories.

Cluster 1 consisted of 45% of households interviewed who accessed their seed on time, in proximity and who had adequate seed. These households were categorised as being "more seed secure" in terms of seed availability. Seed availability was not a challenge for these households as all received their seed before or at the start of the season. Their source of seed was nearby (either from their own village or from a neighbouring village). Over half of these households (57%) also mentioned that the seed from all their seed sources was adequate.

Thirty six percent of households fell into *Cluster 2*, which comprised households that accessed their seed late, with most sourcing seed from far away (57%), and 78% reporting that the seed available from their sources was inadequate. The households falling under Cluster 2 were categorised as "less seed secure" in terms of seed availability since the seed availability indicators were negative. Seed availability was a challenge as all received their seed either mid-season or towards the end of the planting season.

Cluster 3 constituted 19% of sampled households. These households accessed their seed on time (100%), although the distance travelled was far for 95% of them. Sixty three percent indicated that seed available was adequate from their sources. The households falling under this cluster were categorised as "diverse/inconclusive" or varied in terms of seed availability since they gave a mixed picture. Seed availability was not uniform (in terms of timeliness, proximity and adequacy of the quantity) across their crops. While most of this group accessed seed from far, it was acquired on time. A higher proportion viewed their seed as adequate compared to those that did not. This suggests that while proximity is an important aspect for accessing seed, for this group distance was a less important factor affecting timely availability of adequate seed.

These three clusters suggest that there is a wide range of seed availability between households (from more seed secure, less secure, and in between), and that such variations depend on the farmers' crops, varieties, seed sources, location and circumstances. The following account from a farmer in Chaseyama illustrates this variability, suggesting that although he acquired his seed from agro-dealers, NGOs and a government-supported scheme, the seeds were not adequate for his needs.

> "My family struggles to obtain enough seed from agro-dealers, NGOs, and government seed aid. Due to the high cost of seed from agro-dealers, it is difficult to purchase enough of the quantities I need, while the government seed aid comes late and is not guaranteed. The crop seeds that I could not get include groundnuts, cowpeas, Bambara groundnuts and finger millet." (Leo, Life Case History Interview, Chaseyama, September 2017).

Critical issues raised by this farmer included the cost of seed, the timeliness of seed provision, and the reliability of the seed sources. In contrast Tabeth, also from Chaseyama, relied on her own seed which was sufficient for her needs. She explained:

> "For all my seed requirements, I rely on my preserved and stored seed. I do not purchase any seed from the shops. I have enough seeds of sorghum, Bambara groundnuts, groundnuts, finger millet, sunflower and bean varieties (that include mung beans, Karongoda and sweet beans)." (Tabeth, Life Case History Interview, Chaseyama, September 2017).

There were more insecure households in Chikukwa (63%) than in Chaseyama (9%). Overall, a higher proportion (61%) of

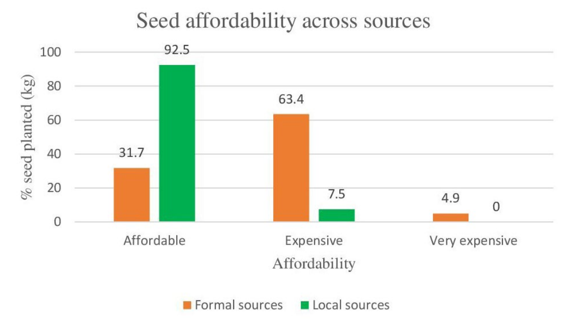

FIGURE 4
How affordable was the seed (note this was limited to purchased seed, excluding own saved seed).

TABLE 3 Results of two-step cluster analysis of Chaseyama and Chikukwa households based on the status of their access to seeds for crops grown in the 2016–2017 season.

Variable	Cluster 1 (42.2%; *n* = 94)	Cluster 2 (34.5%; *n* = 77)	Cluster 3 (23.3%; *n* = 52)
Seed affordability	Affordable (100%)	Expensive (100%)	Affordable (53.8%)
Sex of household head	All male	All male	All female
Age of household head	Mean = 52.7 years	Mean = 49.4 years	Mean = 58.7 years
Number of times receiving seed aid	Mean = 2.2 times	Mean = 3 times	Mean = 2.6 times

Predictor importance (where 1 is high importance, and 0 is low importance): sex = 1; seed affordability = 0.8; age = 0.1; times of receiving seed aid in previous 5 years = 0.04.

households from Chaseyama were seed secure, compared to Chikukwa (29%). The farmers' location determined which seed sources were available, the timeliness of the seed provision, and the distance travelled to obtain seed. Most seed sources for Chikukwa farmers were formal while most for Chaseyama farmers were local. The farmers that accessed most of their seed from local sources were more likely to be seed secure compared to those that accessed their seed from formal sources.

3.4. Seed access by source

Almost all the seed from local sources (93%) was perceived to be affordable compared to seed from formal sources (32%) (Figure 4). Sixty three percent of seed planted and accessed from formal seed sources was considered to be expensive. The "affordability" and "expensive" indicators were based on farmers' perceptions of the cost of seed purchased, thus excluding seed aid. These were seeds purchased from social networks, local markets, agro-input dealers, and local agents of seed companies.

These results suggest that there was a higher probability of farmers acquiring affordable seed from social networks and local markets for their planting needs than from agro-input dealers. The affordability of seed was also analysed by looking at the cost of seed sold by agro-input dealers. Data from agro-input dealers for example, showed that a 10 kg bag of hybrid maize seed sold in Chaseyama ranged from US$18 to US$22, while the same seed quantity sold in Chikukwa shops ranged from US$30 to US$35. This could be related to the remoteness of Chikukwa which is further than Chaseyama from Mutare, the nearest city that provides most of the formal seed. Such factors emphasise the importance of local seed sources for resource-constrained smallholder farmers.

3.5. Seed access at household level

Variables were selected to cluster households based on seed access, and the ability of farming households to acquire seed. These included seed price (affordable or expensive), access to seed aid, the number of times a farmer accessed seed aid, income, asset variables (livestock, homestead assets and land), and demographic variables (gender and age of household head). Seed affordability was assessed in terms of seed prices being affordable, expensive, and very expensive across the different seed sources. A household was given a code of "0" (expensive) if at least one of their seed purchases was perceived to be expensive. A household was given a code of "1" (affordable) if all their seed was considered affordable. This demarcation, though extreme, serves to segregate households by the seed access challenges they experienced. The households that did not incur any challenges of seed access were classified as seed secure. Those households that had at least one challenge were classified as seed insecure. Table 3 shows the results from the cluster analysis after removing variables that did not significantly contribute to the clustering.

Cluster 1 comprised households who perceived their seed to be affordable (42%). These households were categorised as "more seed secure" in terms of seed access since the price of all seed planted was perceived to be affordable by all. This group also received seed aid the least number of times on average (statistically significant, $p < 0.05$). The fact that all household heads under this cluster were older males (mean age of 52.7 years) may serve to support assertions that access to seed could be influenced by the gender of the household head (Beshir and Nishikawa, 2012).

Cluster 2 comprised 35% of the farming households surveyed, which perceived at least one of their seed crops to be expensive. Those in this cluster were categorised as "less seed secure" because of this expense, and also received seed aid the largest number of times. Compared to Cluster 1, male respondents were younger (mean age of 49 years) and less seed secure in terms of seed access. Age in this case could be a contributor to seed access and/or adoption depending on the type of seed as argued by Kinuthia and Mabaya (2017).

Cluster 3 consisted of 23% of households surveyed. Seed was perceived to be "affordable" by 54% and "expensive" by 46% of this group. They were categorised as "diverse/inconclusive" in terms of seed access as the households experienced mixed conditions of seed accessibility. This mixed group comprised only female headed households. The most important variable in clustering the households was gender, followed by affordability (Table 3). Compared to the Cluster 1 male group, the Cluster 3 group had fewer households that perceived their seed to be affordable as they were more resource constrained (shown by a significantly smaller household size, fewer income sources and fewer household assets). However, they received seed aid less frequently than Cluster 2 (less seed secure group). The three cluster categories serve to illustrate the diversity of farmers' seed security (access) as this relates to affordability, age and gender of household head, and seed aid.

The highest proportion of households that received seed aid once or twice over a five-year period was from Chaseyama. In contrast, the highest proportion of households that received seed aid every year was from Chikukwa. Over 5 years, Chikukwa households benefited on average 3.6 times from seed aid compared with Chaseyama farmers (1.9). In the 2016–17 season, about 48% of the 3,894 kg of maize planted in both areas and 17% of sorghum seed, were derived from seed aid. Seed aid is thus an important source of seed for smallholder farmers in Chimanimani. While maize seed was supplied mostly by government, sorghum seed aid was supplied by NGOs such as World Vision. This shows the strong influence of government support towards enabling the formal seed system to supply the main staple cereals to farming households. However, as described, although seed aid has increased seed availability, this is usually provided too late. The modes of seed aid assistance were largely through free distribution (88%), with some through vouchers and seed loans (Figure 5).

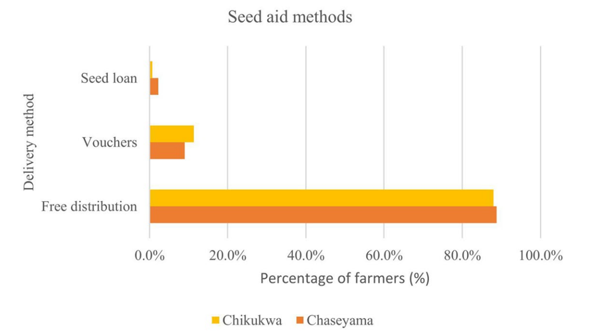

FIGURE 5
Seed aid modalities in Chimanimani.

3.6. Seed utilisation (quality) by source

Households believed that at least 96% of seed planted from both formal and local seed sources did not have physical impurities or any physical damage. These results show that farmers perceived that seed from local sources had comparatively good quality characteristics to that from formal sources. About 96% of seed from formal and local sources was perceived to have good germination. The germination performance of seed from local sources was thus understood to be comparable with seed from formal sources.

A cluster analysis on seed quality was not performed as most farmers perceived their seed to be of good quality. Table 4 presents methods used for seed preservation and storage to ensure good seed quality. The methods mentioned by most farmers in Chaseyama included treating the seeds with ashes and smoking. In Chikukwa, farmers noted the importance of smoking seeds in the kitchen and treating them with a storage chemical (copper shumba). A 48 years-old farmer from Jinga village in Chaseyama gave the following account of the seed preservation techniques he used, based on those used historically by his parents:

> "In order to preserve my seed for the next planting season, I store my sorghum and millet seed in the kitchen to take advantage of the smoke, while the groundnuts, cowpeas and bean seed are stored in permeable sacks. The seed is first treated with ashes of the mukonde tree (*Euphorbia ingens*) and also leaves from the mopane tree (*Colophospermum mopane*). These preservation and storage methods are effective in preserving my seed for future planting. My parents during their time even went further to construct a seed storage house (made from mud and brick). They used storehouses (*Matura*) to keep the seed. These were air-tight so not infiltrated by pests." (Edson, Interview, Chaseyama, 2017).

TABLE 4 Seed preservation and storage methods used by Chaseyama and Chikukwa farmers.

Seed preservation method	Chaseyama (*n* = 114)	Chikukwa (*n* = 113)
Treated with ashes and kept in sacks	23.4%	16.0%
Smoked in the kitchen	22.5%	50.0%
Treated with copper shumba (an inorganic insecticide) and bagged	19.8%	35.8%
Stored legumes unshelled	9.9	—
Use of traditional herbs	—	16.0%
Mixed beans with finger millet residues	—	6.6%

Source: Field survey, 2017.

This finding concurred with an account from Vivian, a 42 years-old woman residing in the village of Munaka in Chikukwa:

> "In order to preserve my maize and finger millet seed, I smoke my personal seed in the kitchen, while the seed intended for sale is mixed with ashes and placed in sacks (that are permeable). I am cautious that the seed mixed with ashes requires the right mixture to prevent discoloration of the seed as this could affect my ability to sell the seed. I am satisfied with these preservation methods as they maintain the quality of my seed." (Vivian, Interview, Chikukwa, 2017).

These accounts of traditional methods of seed preservation and storage corroborate farmers' perceptions of having quality seeds of their own, stored varieties. Farmers with access to adequate land were able to separate food crops from seed crops and prevent cross-pollination of their seed crops. This is a particularly important element for maintaining seed quality for farmers engaged in seed production processes (Wojciech et al., 2022).

4. Discussion

The results show that accessing seed from local sources such as own seed, social networks and local markets, ensures better seed security for smallholder farmers than accessing seed from formal sources such as seed aid and agro-input dealers. Local seed sources were more reliable than formal sources in ensuring that seed was available on time and in closer proximity to households. Seeds sourced locally also showed comparable quality to that from formal sources. Although all seed systems (formal and local) are important for farmers to access seed, the Chimanimani case study shows that local seed channels had a higher likelihood of ensuring improved seed security for smallholder farmers.

A higher proportion of households from Chikukwa was seed insecure than those from Chaseyama. At face value, this is a surprising result since Chikukwa's agro-ecological landscape is more favourable to cropping conditions than Chaseyama, which is drier, hotter and has shallow and mostly infertile soils. Farmers in Chikukwa also received free seed assistance annually, whereas Chaseyama did not. An important distinction between the sites is that Chikukwa is targeted with annual direct seed handouts from government as the area has high potential for crop production. However, despite this potential, results reveal that households did not access adequate seed for their planting needs. The reliance of most Chikukwa farmers on the formal seed system was moreover inadequate, as seed was received too late for effective planting and was available mainly through distant sources.

The situation in Chaseyama was somewhat different. This farming community has less potential to grow a broad range of crops due to their agro-ecological landscape. However, their reliance on the local seed system enabled them to obtain seed that was better adapted to their needs, in a timely manner and sourced closer to them. The local seed system in Chaseyama was characterized by various interventions led by local NGOs such as Participatory Organic Research Extension and Training (PORET) and Towards Sustainable Use of Resources Organisation (TSURO). These organisations assisted farmers with seed fairs, seed exchanges, and farmer-led seed production. The focus of such support was on seeds adapted to farmers' conditions such as small grains (e.g., sorghum and millets) and legumes (e.g., Bambara groundnut and cowpeas).

These findings suggest that because grassroots organisations are involved in supporting farmers to maintain local seed systems, they have the potential to be responsive to farmers' needs. A range of seed access strategies are used, including support to local markets, seed production, and social networks. Formal seed system actors on the other hand, despite providing seed in the district, work through agro-input dealers, and government seed aid provision, and are often remote from farming communities. They are also affected by decisions outside of the farmers' locality which may not support farmers' needs. As examples, agro-input dealers stock less seed (in terms of quantity and diversity) and are limited by their financial position and perceived demand. Moreover, seed is typically not their main business line. Similarly, government seed aid is limited to just a few crops, with central procurement from the capital city Harare usually late and inefficient. Seed is distributed to central district locations that are not always close to farmers, while the targeting of such aid is not transparent, and sometimes based on political connections. Moreover, agro-input dealers are not well distributed in rural locations and struggle with access to working capital, sales, staff management, seed costs and managing demand (Mtisi et al., 2017; Kasoma et al., 2018; Rutsaert et al., 2021).

These factors underscore the importance of managing seed sourcing and distribution to ensure that adequate seed reaches farmers in a timely manner and in reasonable proximity. As a remedy, several researchers suggest adoption of the e-voucher seed supply system provided by the Zambian and Malawian governments (Gough et al., 2002; Kasoma et al., 2018; Ngoma, 2018). These initiatives enable farmers to redeem their vouchers at any agro-input dealer close to them, and to select preferred seed crops. However, this voucher system has also been critiqued regarding its political motives, design and implementation (Mutonodzo-Davies and Magunda, 2012; Kasoma et al., 2018).

The seed access parameters of affordability, seed aid, age and gender of the household head revealed several key findings. Seed from local sources was perceived to be more affordable than seed from formal sources. This was related to seed prices, the social relations of access, and the household's economic status. This finding emphasizes the importance of linkages to local seed sources, particularly for economically constrained households, who are unable to afford seed from formal sources (particularly hybrids). Examining the pricing model of seed from formal sources is critical to ensure that it is affordable for resource-constrained smallholder farmers. Targeted smart subsidies that support both the market and smallholder farmers could be one option of addressing affordability (Dorward et al., 2008; Ward et al., 2021). This is largely important for the staple cereals, and maize in particular, as most are provided via commercial channels.

Seeds from formal and local sources were perceived by farmers to have comparable quality, illustrating confidence in traditional seed quality assurance methods. Despite some studies suggesting that seed from local sources is of poor quality (Otieno et al., 2016; Munyiri, 2020), findings from this research indicate that farmers possess a wealth of indigenous knowledge and experience in maintaining and ensuring the quality of their seed through selection, cleaning, treating, and storage. Several studies corroborate the importance of local knowledge in ensuring quality seed (Ensermu et al., 1998; Bishaw and van Gastel, 2008; Abebe and Alemu, 2017). Badstue et al. (2005) and Bishaw and van Gastel (2008) argue that the social ties among farmers give rise to trust and confidence that the seed supplied from local sources has the desired characteristics and quality. Though the measures used in this study were limited to quality parameters assessed visually (i.e., physical purity and germination), Kusena et al. (2017) confirm that farmers in Chimanimani were able to supply good quality fungal-free seed. Other studies have also noted good germination rates for seed from local sources in Kenya, Ethiopia, Nigeria and Syria (Bishaw et al., 2012; Biemond, 2013; Croft et al., 2017).

The relationship between formal and local seed systems needs further interrogation. Although farmers access seed from both, the systems are not equal. The formal seed system is driven by seed companies and significant donor funding that is focused on developing market-based programmes. Governments in sub-Saharan Africa also provide a conducive policy environment for the formal seed systems to thrive through favourable regional and national policies and regulations that are strongly biased in their favour (Scoones and Thompson, 2011; Westengen et al., 2019; Mulesa, 2021). Support includes farm input subsidy programmes that source and supply farmers with seed, fertilizer, and other inputs from the formal seed system, with a focus on hybrid maize and a few legumes (Mabaya et al., 2017, 2021, 2022). One risk of government-based direct seed distributions is the narrow choices offered to farmers; farmers are also not provided adequate information on which to base their choices. This suggests that market-based approaches to strengthen farmers' access to seed are more effective when linked to appropriate, participatory research and extension.

Local seed systems on the other hand, typically rely on farmer-driven initiatives that have a long history and tradition of storage, selection and exchange. In cases where NGOs exist, and are farmer driven, they can support and enhance such systems. However, the impacts of the formal seed sector on local seed systems are equivocal. Negative impacts include the loss of local varieties, impacts of reduced diversity on food and nutrition security, and, consequently, a reduced ability to adapt to climate change effects (Cramer et al., 2017; Glamann et al., 2017; Khoury et al., 2022). Such impacts have in part been driven by strong policy support for the formal seed sector, alongside the profit-driven interests of seed and agrichemical companies. However, despite policy and regulatory frameworks that favour the formal seed sector, local seed systems have shown resilience during periods of socio-economic and political challenges faced by African nations (Nathaniels and Mwijage, 2000; Mayes et al., 2012; Gill et al., 2013; Chindi et al., 2017). Such experiences are echoed by other studies which show the resilience and capacity of local seed systems to continue to provide diverse and adapted varieties despite national seed laws that are biased towards the commercial seed system and the growth and expansion of certified seed (Almekinders, 2002; Visser, 2015; Herpers et al., 2017).

5. Conclusion

The findings of this study clearly show the prominent and under-appreciated role of local seed systems in providing smallholder farmers with more diverse access to affordable and timely seeds in proximity to their homesteads. Seeds sourced locally also showed comparable quality to that from formal sources. An important conclusion points towards the need for strengthened efforts towards understanding and supporting local seed systems as the main contributor to improving seed security for resource-constrained households. The formal seed systems should be regarded as complementary, rather than central, in ensuring access to specific crops and traits that farmers need but which are not met by local seed systems. This is only possible if channels that use formal seed systems are brought closer to farmers, offer affordable seeds in a timely manner, and are carefully tailored to a participatory process that involves farmers in identifying their needs and constraints.

Methodologically, the use of cluster analysis in this study helped to determine seed security status of farming households, providing a granular analysis of the constraints they face at the site level. This approach will be valuable for future household and location-specific seed security assessments in guiding development and policy interventions.

We conclude that no single seed system is able to serve the needs of all farmers, but efforts to date have neglected the importance of local seed systems and their contribution to seed, food and nutrition security. Seed interventions and related policies need to take account of the social, ecological, political and cultural contexts of a farmer's environment, and should be anchored on principles of inclusivity and farmer participation. Given the history of neglect, we propose redress by increasing resources and policy support for local seed systems as a way of ensuring improved seed security for smallholder farming households.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Research Ethics Committee of the Faculty of Science, University of Cape Town, South Africa (FSREC 074-2016). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

BN designed and performed the research, collected and analysed the data, and led the writing of the manuscript. RW supervised and part-funded the doctoral research and supported its conceptualization, the data collection, the interpretation of the information, and the writing of the manuscript. SM co-supervised the doctoral research and supported its conceptualization, and the design, analysis, and interpretation of the information, and assisted with the writing of the manuscript. All authors contributed to the article 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

References

Abebe, G., and Alemu, A. (2017). Role of improved seeds towards improving livelihood and food security at Ethiopia. *Int. J. Res.-Granthaalayah* 5, 338–356. doi: 10.29121/granthaalayah.v5.i2.2017.1746

AGRA (2014). "Planting the seeds for a green revolution in Africa" in *Alliance for a green revolution in Africa report, 2014*. (AGRA, Nairobi)

Almekinders, C. J. M. (2002). The importance of informal seed sector and its relation with the legislative framework. Paper presented at GTZ-Eschborn, July 4–5, 2000. Available at: https://api.semanticscholar.org/CorpusID:16647441.

Almekinders, C. J., and Louwaars, N. P. (2002). The importance of the farmers' seed systems in a functional national seed sector. *J. New Seeds* 4, 15–33. doi: 10.1300/J153v04n01_02

Almekinders, C. J., Walsh, S., Jacobsen, K. S., Andrade-Piedra, J. L., McEwan, M. A., de Haan, S., et al. (2019). Why interventions in the seed systems of roots, tubers and bananas crops do not reach their full potential. *Food Secur.* 11, 23–42. doi: 10.1007/s12571-018-0874-4

Badstue, L. B., Bellon, M. R., Berthaud, J., Ramírez, A., Flores, D., Juárez, X., et al. (2005). "Collective action for the conservation of on-farm genetic diversity in a center of crop diversity: an assessment of the role of traditional farmers' networks" in *CAPRi working paper # 38* (Washington, DC: IFPRI)

Bengtsson, F. (2007). Review of information available on seed security and seed aid interventions in Ethiopia, Eritrea, Mali and Sudan. *Drylands coordination group, Norway. Report no. 51 (10, 2007)*. Available at: https://www.eldis.org/document/A33825.

Beshir, B., and Nishikawa, Y. (2012). An assessment of farm household diverse common bean seed sources and the seed quality in Central Ethiopia. *Trop. Agric. Dev.* 56, 104–112. doi: 10.11248/jsta.56.104

Biemond, C. (2013). "Seed quality in informal seed systems" in *PhD thesis* (Wageningen: Wageningen University)

Bishaw, Z., Struik, P. C., and Van Gastel, A. J. G. (2012). Farmers' seed sources and seed quality: physical and physiological quality. *J. Crop Improv.* 26, 655–692. doi: 10.1080/15427528.2012.670695

Bishaw, Z., and van Gastel, A. J. G. (2008). ICARDA's seed-delivery approach in less favorable areas through village-based seed enterprises: conceptual and organizational issues. *J. New Seeds* 9, 68–88. doi: 10.1080/15228860701879331

Brumel, P. J., , Remington, , T., . (2004). Relief seed assistance in Zimbabwe in Sperling T. Remington, , , J. M. Haugen, and , and S. Nagoda, . *Addressing seed security in disaster response: linking relief with development*. Cali: International Centre for Tropical Agriculture.

Chindi, A., Shunka, E., Solomon, A., Gebremedhin, W. G., Seid, E., and Tessema, L. (2017). Participatory potato seed production: a breakthrough for food security and income generation in the central highlands of Ethiopia. *Open Agric.* 2, 205–212. doi: 10.1515/opag-2017-0021

CIAT, CRS, CARE, USAID. (2012). *Seed aid for seed security: advice for practitioners. Practice brief 1*. CIAT, Colombia. Available at: https://www.crs.org/sites/default/files/tools-research/seed-aid-for-seed-security.pdf.

CIAT, CRS, SNS-MARDNR, UEA, FAO, World Concern, Save the Children, ACDI/VOCA, Save the Children and World Vision. (2010). *Seed system security assessment, Haiti*. Arusha: International Center for Tropical Agriculture

CIAT, CRS, World Vision, Care, AGRITEX and CIMMYT. (2009). *Seed system security assessment, Zimbabwe*. Rome: International Center for Tropical Agriculture

CIAT, FAO, MAF-GoSS, AAH-I, ACTED, ADRA, AMURT, CRS, DRC, NPA. (2011). *Seed system security assessment, southern Sudan, November–December 2010*. Juba: FAO and CIAT.

Cramer, W., Egea, E., Fischer, J., Lux, A., Salles, J. M., Settele, J., et al. (2017). Biodiversity and food security: from trade-offs to synergies. *Reg. Environ. Chang.* 17, 1257–1259. doi: 10.1007/s10113-017-1147-z

Croft, M. M., Marshall, M. I., Odendo, M., Ndinya, C., Ondego, N. N., Obura, P., et al. (2017). Formal and informal seed systems in Kenya: supporting indigenous vegetable seed quality. *J. Dev. Stud.* 54, 758–775. doi: 10.1080/00220388.2017.1308487

Dalle, S. P., and Westengen, O. T. (2020). Seed security in theory and practice: a comparative study of seed security frameworks and their use. *Noragric Report No. 86*. Available at: https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/2732942.

Dorward, A., Chirwa, E., Boughton, D., Crawford, E., Jayne, T., Slater, R., et al. (2008). "Towards "smart" subsidies in agriculture? Lessons in recent experience in Malawi" in *Natural resources perspectives 116*. Malawi: Ministry of Agriculture and Food Security. Available at: https://eprints.soas.ac.uk/id/eprint/5130.

Ensermu, R., Mwangi, W., Verkuijl, H., Hassena, M., and Alemayehu, Z.. (1998). *Farmers' wheat seed sources and seed management in Chilalo Awraja, Ethiopia*. Mexico: IAR and CIMMYT.

FAO (2015a). *Household seed security concepts and indicators. Discussion paper. Building capacity for seed security assessments*. FAO, Rome: Food and Agriculture Organization and European Commission Humanitarian Aid. Available at: https://www.fao.org/fileadmin/user_upload/food-security-capacity-building/docs/Seeds/SSCF/Seed_security_concepts_and_indicators_FINAL.pdf.

FAO (2015b). *Seed security assessment. A practitioner's guide. Building capacity for seed security assessments. Version 1*. FAO, Rome: Food and Agriculture Organization and European Commission Humanitarian Aid.

FAO (2016). *Seed security assessment: a practitioner's guide* Rome Food and Agriculture Organisation.

Gill, T. B., Bates, R., Bicksler, A., Burnette, R., Ricciardi, V., and Yoder, L. (2013). Strengthening informal seed systems to enhance food security in Southeast Asia. *J. Agric. Food Syst. Commu. Dev.* 3, 139–153. doi: 10.5304/jafscd.2013.033.005

Glamann, J., Hanspach, J., Abson, D. J., Collier, N., and Fischer, J. (2017). The intersection of food security and biodiversity conservation: a review. *Reg. Environ. Chang.* 17, 1303–1313. doi: 10.1007/s10113-015-0873-3

Gollin, D. (2014). *Smallholder agriculture in Africa: an overview and implications for policy IIED working paper*. IIED, London.

Gough, A. E., Gladwin, C. H., and Hildebrandy, P. E. (2002). Vouchers versus grants of inputs: evidence from Malawi's starter pack program. *Afr. Stud. Q.* 6, 203–222.

Herpers, S., Vodouhe, R., Halewood, M., and De Jonge, B. (2017). "The support for farmer-led seed systems in African seed laws" in ISSD Africa: ISSD Synthesis paper. KIT Working Papers 2017-9. Nairobi (Kenya): ISSD Africa. Available at: https://hdl.handle.net/10568/81545.

Kansiime, M. K., and Mastenbroek, A. (2016). Enhancing resilience of farmer seed system to climate-induced stresses: insights from a case study in West Nile region, Uganda. *J. Rural. Stud.* 47, 220–230. doi: 10.1016/j.jrurstud.2016.08.004

Kasoma, A. C., Nyemba, E. N., and Deka, B. (2018). *Implementation of the E-voucher in Zambia; challenges and opportunities*. Zambia: Policy Monitoring and Research Centre. Available at: https://www.pmrczambia.com/wp-content/uploads/2018/12/E-Voucher-Analysis-2018.pdf.

Khoury, C. K., Brush, S., Costich, D. E., Curry, H. A., de Haan, S., Engels, J. M., et al. (2022). Crop genetic erosion: understanding and responding to loss of crop diversity. *New Phytol.* 233, 84–118. doi: 10.1111/nph.17733

Kinuthia, B. K., and Mabaya, E. (2017). The impact of agricultural technology adoption on farmer welfare in Uganda and Tanzania. *Partnership from economic policy brief number 163*. New York: Cornell University. Available at: http://barrett.dyson.cornell.edu/staars/fellows/files/Kinuthia_Mabaya%201%20Jan%202017.pdf.

Kusena, K., Wynberg, R., and Mujaju, C. (2017). Do smallholder farmer-led seed systems have the capacity to supply good-quality fungal-free sorghum seed? *Agric. Food Secur.* 6:52. doi: 10.1186/s40066-017-0131-7

Lin, B. B. (2011). Resilience in agriculture through crop diversification: adaptive management for environmental change. *Bioscience* 61, 183–193. doi: 10.1525/bio.2011.61.3.4

Louwaars, N. P., and de Boef, W. S. (2012). Integrated seed sector development in Africa: a conceptual framework for creating coherence between practices, programs, and policies. *J. Crop Improv.* 26, 39–59. doi: 10.1080/15427528.2011.611277

Louwaars, N. P., De Boef, W. S., and Edeme, J. (2013). Integrated seed sector development in Africa: a basis for seed policy and law. *J. Crop Improv.* 27, 186–214. doi: 10.1080/15427528.2012.751472

Mabaya, E., Kachule, R., Waithaka, M., Mugoya, M., Kanyenji, G., and Tihanyi, K. (2021). *Malawi 2021 country study—the African seed access index (version August 2021)*. Available at: https://ageconsearch.umn.edu/record/317014.

Mabaya, E., Miti, F., Mwale, W., and Mugoya, M. (2017). *Zambia brief 2017—the African seed access index*. New York: Cornell University Available at: www.tasai.org/reports.

Mabaya, E., Mujaju, C., Nyakanda, P., Waithaka, M., Mugoya, M., Damba, B., et al. (2022). *Zimbabwe country report—the African seed access index*. New York: Cornell University.

Mayes, S., Massawe, F. J., Alderson, P. G., Roberts, J. A., Azam-Ali, S. N., and Hermann, M. (2012). The potential for underutilized crops to improve security of food production. *J. Exp. Bot.* 63, 1075–1079. doi: 10.1093/jxb/err396

Mazvimavi, K., Murendo, C., Gwazvo, C., Mujaju, C., and Chivenge, P. (2017). *The impacts of the El Niño-induced drought on seed security in Zimbabwe: implications for humanitarian response and food security*. ICRISAT, Patancheru: ICRISAT, CRS and FAO. Available at: http://oar.icrisat.org/10279/.

McGuire, S. J., 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

McGuire, S. J., and Sperling, L. (2016). Seed systems smallholder farmers use. *Food Secur.* 8, 179–195. doi: 10.1007/s12571-015-0528-8

Mtisi, S., Dube, A., and Dube, T. (2017). Assessing the challenges faced by rural agro-dealers in Matabeleland North Province, Zimbabwe. *Afr. J. Bus. Manag.* 11, 183–193.

Mugandani, R., Wuta, M., Makarau, A., and Chipindu, B. (2012). Reclassification of agroecological regions of Zimbabwe in conformity with climate variability and change. *Afr. Crop. Sci. J.* 20, 361–369.

Mujaju, C. (2010). *Zimbabwe seed sector. A baseline study of Zimbabwe seed sector for use in the rationalisation and harmonization of the seed regulations and policies in the COMESA Member States*. AFTSA, Nairobi: African Seed Trade Association. Available at: https://www.afsta.org/wp-content/uploads/2022/10/ZAMBABWE-SEED-SECTOR-BASELINE-STUDY.pdf.

Mujaju, C., Mashonjwa, E., Kasasa, P., and Otieno, G. (2017). "Climate-resilient seed systems and access and benefit-sharing in Zimbabwe" in *Exchanging genetic resources in a changing climate*. (ISSD Africa) 82. Available at: https://cgspace.cgiar.org/handle/10568/89859.

Mulesa, T. H. (2021). Politics of seed in Ethiopia's agricultural transformation: pathways to seed system development. *Front. Sustain. Food Syst.* 5:742001. doi: 10.3389/fsufs.2021.742001

Mulesa, T. H., Dalle, S. P., Makate, C., Haug, R., and Westengen, O. T. (2021). Pluralistic seed system development: a path to seed security? *Agronomy* 11:372. doi: 10.3390/agronomy11020372

Munyiri, S. W. (2020). "Opportunities for quality seed production and diffusion through integration of the informal Systems in sub-Saharan Africa" in *Prime archives in agricultural research*. ed. J. S. Dias (Vide Leaf: Hyderabad)

Mutonodzo-Davies, C., and Magunda, D. (2012). The politics of seed relief in Zimbabwe. *IDS Bull.* 42, 90–101. doi: 10.1111/j.1759-5436.2011.00239.x

Nathaniels, N. Q., and Mwijage, A. (2000). *Seed fairs and the case of Marambo village, Nachingwea district, Tanzania: Implications of local informal seed supply and variety development for research and extension*. London: Overseas Development Institute.

Ngoma, H.. (2018). E-vouchers bring welcome choice to Zambia farmers. *AgriLinks*. Available at: https://agrilinks.org/post/policy-reform-boosts-business-and-promotes-diversification-e-voucher-program-zambia-0

Otieno, G., Noriega, I. L., and Reynolds, T. W. (2016). *Smallholder access to quality and diverse seed in Uganda: implications for food security*. Rome (Italy): Bioversity International 4. Available at: https://hdl.handle.net/10568/78822.

Oxfam (2016). Our seeds. *Lessons from the drought: voices of farmers in Zimbabwe. Joint agency briefing note*. Oxfam GB, Oxford

Oxfam-UNDP/GEF. (2015). Scaling up adaptation in Zimbabwe, with a focus on rural livelihoods project. *Technical report*, Harare, Zimbabwe: Oxfam Southern Africa Wordpress. Available at: https://oxfamsouthernafrica.wordpress.com/2019/10/11/scaling-up-adaptation-in-zimbabwe-with-a-focus-on-rural-livelihoods-project/#:~:text=The%20Oxfam%2DUNDP%2FGEF%20Scaling,Ministries%20of%20Environment%2C%20Water%20and.

Pindiriri, C., Chirongwe, G., Nyagena, F. M., and Nkomo, G. N.. (2021). Agricultural free input support schemes, input usage, food insecurity and poverty in rural Zimbabwe. *Advanced policy-focused poverty analysis in Zimbabwe*. Zimbabwe Economic Policy Analysis and Research Unit Available at: https://zepari.co.zw/sites/default/files/2022-03/Agricultural%20free%20input%20support%20schemes.pdf. (Accessed June 3, 2023)

Remington, T., Maroko, J., Walsh, S., Omanga, P., and Charles, E. (2002). Getting off the seed and tools treadmill with CRS seed vouchers and fairs. *J. Disaster Stud. Policy Manag.* 26, 302–315. doi: 10.1111/1467-7717.00209

Ruane, J., Mba, C., and Xia, J. (2022). Proceedings of the Global Conference on Green Development of Seed Industries. 4–5 November, 2021. Rome, FAO.

Rutsaert, P., Donovan, J., and Kimenju, S. (2021). Demand-side challenges to increase sales of new maize hybrids in Kenya. *Technol. Soc.* 66:101630. doi: 10.1016/j.techsoc.2021.101630

Scoones, I., and Thompson, J. (2011). The politics of seed in Africa's green revolution: alternative narratives and competing pathways. *IDS Bull.* 42, 1–23. doi: 10.1111/j.1759-5436.2011.00232.x

Shrestha, P., (2020). *Participatory seed security assessment and action plan: a guide*. Ottawa, SeedChange, p. 170.

Sperling, L., and Cooper, H. D. (2003). "Understanding seed systems and strengthening seed security: a background paper" in *Improving the effectiveness and sustainability of seed relief: a stakeholders' workshop* (Rome: Food and Agriculture Organization). Available at: https://cgspace.cgiar.org/handle/10568/53005.

Sperling, L., Gallagher, P., McGuire, S., March, J., and Templer, N. (2020). Informal seed traders: the backbone of seed business and African smallholder seed supply. *Sustainability* 12:7074. doi: 10.3390/su12177074

Sperling, L., and McGuire, S. J. (2010). Persistent myths about emergency seed aid. *Food Policy* 35, 195–201. doi: 10.1016/j.foodpol.2009.12.004

Sperling, L., Ortiz, O., and Thiele, G. (2013). Roots, tubers and bananas. *Conceptual frameworks for guiding practical interventions. Working paper 2013-1*. CIP, Bioversity International, CIAT, and IITA. Available at: https://cgspace.cgiar.org/handle/10568/72975.

Visser, B. (2015). *A summary of the impact of national seed legislation on the functioning of small-scale farmers' seed systems in Peru, Vietnam and Zimbabwe*. Oxfam/NOVIB, Netherlands. Available at: https://sdhsprogram.org/assets/2015/12/IFAD_seedlaw-study_a-summary-of-the-impact-of-national-seed-legislation_Peru-Vietnam-Zimbabwe.pdf.

Walsh, S., Potts, M., Remington, T., Sperling, L., and Turner, A. (2014). *Seed storage brief #1: Defining seed quality and principles of seed storage in a smallholder context*. Nairobi: Catholic Relief Services.

Ward, P. S., Mapemba, L., and Bell, A. R. (2021). Smart subsidies for sustainable soils: evidence from a randomized controlled trial in southern Malawi. *J. Environ. Econ. Manag.* 110:102556. doi: 10.1016/j.jeem.2021.102556

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

Westengen, O. T., Haug, R., Guthiga, P., and Macharia, E. (2019). Governing seeds in East Africa in the face of climate change: assessing political and social outcomes. *Front. Sustain. Food Syst.* 3:53. doi: 10.3389/fsufs.2019.00053

Wojciech, L., S Tsiami, A., and Ryan, P. (2022). Self-pollinating crop isolation techniques for micro scale gardeners with limited access to arable land. A mini review. *Acta Sci. Nutr. Health* 6, 73–82. doi: 10.31080/ASNH.2022.06.1050