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Contribution of Community Seed Banks to farmer seed systems and food security in Northern and Central Malawi

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A B S T R A C T

Community Seed Banks (CSBs) are promoted as an approach to support farmers' access to quality seeds of adapted varieties. While the adoption and impact of varieties distributed through conventional formal seed systems have been extensively studied, research on how participation in CSBs relates to farmers' seed systems and food security is limited. This paper uses survey data covering 688 households and 1600 plots from Northern and Central Malawi, combined with historical climate data, to assess the extent to which farmers are utilizing CSBs as a seed source and the association of farmer participation in CSBs with a range of other foods system variables. We find that CSBs are the source of about 1/3 of the seeds of maize, groundnut, and soyabean used by the participants and that they source less of their seeds from their own harvest compared to non-participants. While the use of CSB seeds of different crops shows mixed associations with yields at the plot-level, we find that CSB participation is positively associated with higher household food security overall. Furthermore, we find a positive association between exposure to high mean temperatures and rainfall shortages and the propensity to participate in CSBs, suggesting CSBs play a role in adaptation. This study thus shows that CSB participation is associated with several positive food system outcomes, but more research is needed to understand the causal links as well as the efficiency of CSBs compared to other approaches to strengthen farmers' seed security.

1. Introduction

There is widespread agreement about the importance of enhancing access to quality seeds of well-adapted varieties for enhancing agricultural productivity and food security (Almekinders et al., 2019; Coomes et al., 2015; Kansiime and Mastenbroek, 2016; Madin et al., 2022; McGuire and Sperling, 2011; Nabuuma et al., 2022). Nowhere is this more important than in low-income countries where most of the rural population derive their livelihood from agriculture, are highly affected by climate change, and face food insecurity (FAO et al., 2022). Community Seed Banks (CSBs) have emerged as an increasingly popular institutional approach to support farmers' access to seeds.

In their original form, CSBs focused on the conservation and distribution of local varieties not offered by actors in the formal seed system (Love and Spaner, 2007; Vernooy et al., 2014). More recently, CSBs in some parts of the world have expanded their activities to encompass the production and dissemination of seeds of improved varieties from breeding programs (Joshi et al., 2018; Okori et al., 2022). Typically, CSBs distribute seeds through revolving seed loan schemes: Farmers get seeds before planting and pay back with the same or a somewhat higher volume of seeds from their harvest (Vernooy et al., 2014). Seed quality relies on the existence of appropriate governance frameworks, training, and quality assurance systems (Shrestha et al., 2015). Depending on what is available from the CSBs, a farmer will choose the crop, variety,

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and quantity they will borrow and repay after harvest. This process is intended to reduce transaction costs and allow low-income farm households to access seeds without credit.

In most African countries, including Malawi, formal and informal seed systems play complementary roles in supplying seeds to farmers (Louwaars and De Boef, 2012). The formal seed system supplies certified seeds of improved varieties. Farmers' seed systems, sometimes referred to as informal seed systems, include seed sourcing from their own harvest (farm-saved seeds), social networks (farmer-to-farmer seed exchange), and local informal markets. CSBs can be seen as a type of intermediary seed system organization, combining elements from both formal and informal seed systems (Sisay et al., 2017; Westengen et al., 2023).

A small but growing body of literature has investigated associations between CSB participation and other farm and livelihood factors. A study by Bezabih (2008) from Ethiopia reported that CSB participants have higher farm-level agrobiodiversity and increased crop productivity. Gautam et al., (2020) reported positive direct and spillover associations on maize yields, income, and female leadership opportunities among participants in community seed-producing groups in Nepal. In Malawi, Okori et al., (2022) found CSBs to enhance farmers' access to improved varieties of legumes and neglected and underutilized crops, resulting in higher yields of common beans, groundnuts, and pigeon peas for CSB beneficiaries compared to non-beneficiaries. From Northern Malawi, Vansant et al., (2022) reported that CSBs strengthen local seed systems by providing a platform for the exchange of knowledge and varieties and that CSBs increase the availability of local maize varieties preferred for post-harvest characteristics like poundability, storage, taste, and color. A recent qualitative study by Meixner Vásquez and Andersen (2023), also from Northern Malawi, reported that CSBs contribute to all four dimensions of food security (availability, access, utilization, and stability) amongst the participants. Vernooy et al. (2017) qualitatively investigated the role of CSBs in Bhutan, South Africa, Uganda, and Brazil and reported that by promoting conservation and ensuring access to seeds, CSBs can help farmers cope with climate change. This notion is also reflected in the sixth assessment report of the Intergovernmental Panel on Climate Change, which mentioned CSBs as an example of an effective community-based adaptation approach (IPCC, 2022). This article complements earlier work by presenting a rigorous quantitative study of the association between CSB participation and seed sourcing and crop yields of maize, groundnuts, and soyabean, as well as food security and how climate factors correlate with participation decisions.

The main mechanism supporting farmers' access to certified seeds at an affordable price in Malawi is the agricultural input subsidy program currently called the Affordable Input Program [AIP].[1] The objective of the AIP is to contribute to food security, improve nutrition, and reduce poverty by increasing farmer's access to improved inputs such as certified seeds of selected crops (maize and, in some years, also legumes) and inorganic fertilizer (Arndt et al., 2016; Khonje et al., 2022; Walls et al., 2023). Agricultural input subsidy program design in Malawi has changed over the years in terms of program name, number of beneficiaries, subsidized package and redeeming price. A brief history of the program scale (number of beneficiaries) is the earlier Starter Park program introduced in 1997 targeted 2.8 million farm households, the Target Input Program targeted 1.5 million household in 2000, and the Extended Target Input Program targeted 1.7 million households in 2003 (Holden, 2019). The program was at its largest in terms of input package and success stories in terms of high maize yields under Bingu wa Mutharika in 2008/09 (Holden, 2019). Since the 2020/21 season, the macroeconomic situation in Malawi has undergone significant changes. The size of the program increased in terms of the number of beneficiaries, from targeting 900,000 beneficiaries under the Farm Input Subsidy program (FISP) in the year 2019/20 to about 3.8 million beneficiaries under AIP in the year 2020/21. The other change has been in the higher redeeming prices a narrower range and type of inputs supplied (Benson et al., 2024). However, despite the allocation of a large share of the national budget for agriculture to this input subsidy program, only a small share of the seeds planted by Malawian rural farmers are sourced from the formal system (Chibwana et al., 2014; Khonje et al., 2022; Mason and Ricker-Gilbert, 2013).[2]

In Ethiopia and Uganda, the governments have endorsed so-called Integrated Seed System Development policies providing legal space and support to intermediary seed system actors like CSB (AU, 2011; National MoA 2017; MAAIF 2018). In Malawi, CSBs are not recognized and supported in the National Seed Policy of 2018 and are also not formally recognized and supported in the current National Seed Act of 2022. CSBs have, therefore, been established by Non-Governmental Organizations (NGOs) outside the conventional formal seed system and its rules and regulations. While differing in specific objectives, CSBs share the objective of enhancing farmers' access to adapted varieties, often of crops and varieties subject to limited investment by the private sector, like legumes (Haug et al., 2023).

In this article, we address three interrelated questions: 1) To what extent are farmers utilizing CSBs as a seed source? 2) Is participation in CSBs correlated with higher crop yields and higher household food security? and 3) What is the correlation between past exposure to climate shocks and participation in CSBs? We rely on comprehensive cross-sectional data that combines household and plot-level datasets and use the Propensity Score Matching (PSM) method to assess the possible correlation of farmers' participation in CSBs to crop yields and household food security, accounting for possible confounding effects from observable heterogeneity. Comparing CSB participants with non-participants, we assess the association of participation on crop yields for maize, groundnuts, and soyabean at the plot level and on food insecurity (measured by three experiential indicators) at the household level. The PSM method helps reduce (but does not eliminate) the potential endogeneity associated with participation in CSBs and household livelihood outcomes. Thus, we use a combination of PSM and a household-plot panel fixed effects model to analyze the household plot-level data and assess differences in crop yield levels between plots with CSB seeds and those with seeds sourced from other sources. Likewise, in the household-level analysis, we use the PSM method to assess the correlation between participating in CSBs and household food security. Furthermore, we perform a sensitivity analysis of our PSM estimates by computing Rosenbaum bounds (Rosenbaum, 2002) for the Average Treatment Effect on the Treated (ATT) to assess the potential influence of unobserved heterogeneity on the results.

Study results show that for participants, the CSB is the source of about 1/3 of the seeds of maize, groundnut, and soyabean used, and compared to non-participants, they source less of their seeds from their own harvest. Addressing our research question on associations between CSB participation, crop yields and food security, we find mixed plot-level yield correlations but a positive association between participation in CSBs and food security. When studying the associations between various socioeconomic and agroecological factors and CSB participation, we find that exposure to high historical mean temperatures and past experiences of rainfall shortages correlates positively with the propensity to participate in CSBs. We note that our results provide information on the direction and strength of correlations but may not necessarily imply causal impacts.

[1] In Malawi, the input subsidy program changed its name in the 2019/2020 agricultural season from the Farm Input Subsidy Program (FISP) to the Affordable Input Program (AIP).

[2] Figure A in the supplementary material shows the trend of the supply of subsidized inputs for the past six years in the study area.

2. Conceptual framework

This section explains the hypothesized links between participating in seed systems, crop yields, household food security, and climate variability. Farmers can access seeds from various seed sources within the seed system and depending on factors such as crop and variety preferences, climate variability, and individual circumstances, they may opt to use their own-saved seeds or supplement them with seeds from off-farm sources. This decision is dynamic and, thus, varies between years depending on the specific context of each farmer. Off-farm seed sources encompass a range of options, including social relations (farmer-to-farmer seed exchange), local markets, agrodealers, input subsidy programs, and community seed groups such as CSBs. Hence, seed-sourcing choices made by farmers could be influenced by a complex interplay of demand and supply factors.

A farmer's decision to participate in CSBs depends on the perceived benefits of participation. Participating in CSBs entails farmers' access to seeds through loan schemes, which ease seed access constraints (Bezabih, 2008) and a platform for exchanging knowledge and varieties (Vansant et al., 2022). CSBs offer farmers local and improved varieties, hence potentially diversifying their crop and variety portfolio. A diversified cropping portfolio allows farmers to mitigate the impacts of climate variability and change by reducing the risk of total crop failure and offering alternative income sources (Lin, 2011; Love and Spaner, 2007). Also, a diversified cropping portfolio allows farmers to have access to seeds of crops and varieties they prefer and demand. In this study, we assess how participation in CSBs through access to seeds could potentially help increase the productivity of farm members. For this link to be realized, the varieties from CSBs must perform better according to farmers' preferences and be adapted to local conditions to increase farm-level productivity. As we rely on survey data, we are unable to include seed quality *per se* as a variable in our analysis and are, therefore, unable to distinguish between varietal quality and seed quality when we include "CSB seeds" as a variable in the plot level analysis. In addition to the varieties used, farm characteristics and other inputs play important roles in crop yields; hence, we include them in the analysis as controls.

The next step in our analysis is to assess the correlation between participating in CSBs and indicators of household food security status. We hypothesize that CSB participants are more food secure than non-participants, either because of yield and income benefits from using CSB seeds or because CSB participation increases their social capital and, thereby, access to food (Madsen et al., 2021; Meixner Vásquez and Andersen, 2023). McGuire and Sperling (2011) indicate that a possible link between food and seed security lies in access. Direct production to consumption is thus the first potential channel to increase the consumption of nutritious food for rural farmers in Malawi (Gelli et al., 2020). The second channel involves a broader role of CSBs as a social network building knowledge on seed varieties and, ultimately, improving access to more nutritious food (Song, et al, 2021; Meixner Vásquez and Andersen, 2023). In this study, we proxy household food security using subjective experiential measures of household food security (food insecurity access score, number of food insecure months, and probability that the household had to worry about not having enough food). While food security has many dimensions (Clapp et al., 2022; FAO, et al, 2022), this paper is limited to measuring the availability and access dimensions.

As discussed above, a farmer's decision to participate in CSBs is based on multiple internal and external factors. We hypothesize that exposure to climatic shocks is among the external factors influencing participation in CSBs. We assume that exposure to climatic shocks can create the need for new and better-adapted seeds. Exposure to climate variability and shocks may increase farmers' awareness of the risks associated with relying on limited seed sources or a single crop or variety. Farmers are known to shift from their business-as-usual approach when facing increasing uncertainty (Angelsen and Dokken, 2018; Takasaki, 2011). Previous research has shown that drought exposure interacts with farmers' risk preferences, leading to increased adoption of drought-tolerant maize varieties in Malawi (Holden and Quiggin, 2017). Exposure to climatic shocks also influences farmers' seed choices, prompting them to select drought-tolerant varieties (Katengeza et al., 2019) and even switch to different seed types and channels (Makate et al., 2022, 2023). We acknowledge that beyond the climatic factors, an interplay of socioeconomic and institutional variables, seed systems characteristics, plot-level characteristics, and farmers' behaviour can all influence participation (Acevedo et al., 2020). Hence, we include these factors in our analysis as controls. We acknowledge that other unobservable factors are not incorporated in the analysis because of data limitations.

3. Materials and methods

3.1. Data and study context

Data for this study comes from a household survey conducted in five districts in Central and Northern Malawi between July and August 2022. Data collection captured production and harvest of the 2021–2022 agricultural season. The five districts are Dowa, Kasungu, and Mchinji in Central Malawi and Rumphi and Mzimba in Northern Malawi (Fig. 1). The sampled districts were selected because they have active CSBs. Kasungu, Mchinji, and Dowa districts lie in the Kasungu-Lilongwe plain, which is relatively flat. These districts are well known for their fertile soil and have a history of productive agriculture and extensive cultivation of maize and legumes. Soil types vary from sandy clay loam soils in Kasungu to pure sandy soils in Dowa. Rumphi and Mzimba districts lie in the high-altitude agroecology (>1300 m above sea level), with ≤1000 mm of yearly rainfall (Okori et al., 2022). Soil types vary from sandy soils to clay soil. Agriculture in the sampled districts is mostly rain-fed.

In Malawi, CSBs have been established over the last decade to support seed supply of legumes, local maize and neglected and underutilized crops. Andersen et al., (2022) categorised CSBs in Malawi as either agrobiodiversity-focused CSBs or crop-specific seed multiplication and distribution CSBs. Agrobiodiversity-focused CSBs emphasize strengthening the informal or farmers' seed systems, while crop-specific seed multiplication and distribution CSBs focus on finding alternative pathways to reach farmers for varieties developed in the formal system. Our study includes both types.

The CSBs in Rumphi district were first established in year 2010/11 by the organization Find your Feet (FyF) and later transferred support to the Biodiversity Conservation Initiative (BCI) (Meixner Vásquez and Andersen, 2023). The primary goal of this CSB is to conserve, store and multiply local crop varieties such as maize, groundnuts, beans, bambara nuts, and other neglected and underutilized crops. The Rumphi CSB has more than 51 local crop varieties, of which four maize varieties have

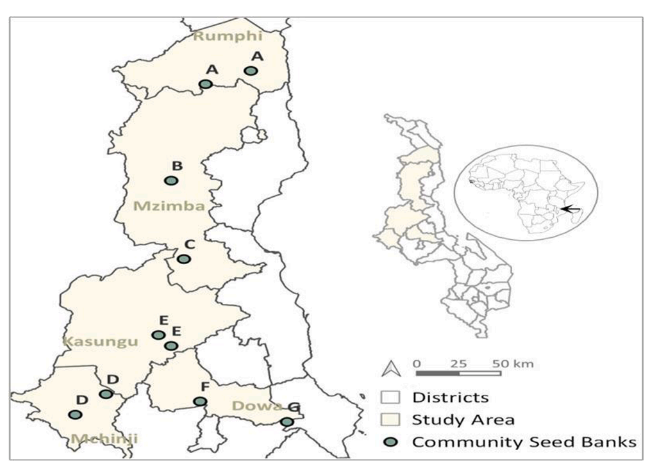

Fig. 1. Map of the study districts and location of the study sites.

been improved through participatory plant breeding (Meixner Vásquez and Andersen, 2023). Some of the local varieties of maize are *Kafula wa yellow, Lokolo, and Bingo*, varieties for groundnuts are *Chalimbana, Kaswaya, and Chalimbana wa khakhi*. Following this, an additional two (2) CSBs were established in the same district, also those supported by BCI. In Kasungu and Mchinji, CSBs are set up with a focus on multiplying improved varieties of groundnuts and beans, supported by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Cooperative for Assistance and Relief Everywhere (CARE). Some of the improved varieties available for groundnuts are *Chalimbana, CG7, CG9, CG10* and *Nsinjiro*. In Dowa, the establishment of CSBs is supported by the National Smallholder Farmers' Association of Malawi (NASFAM) with the goal of multiplying and storing seeds of the improved soyabean varieties *Tikolole* and *Nasoko*, while another CSB is supported by School for Agriculture for Family Independence (SAFI) focusing on multiplying and storing seeds of the local variety known as *Yellow* maize high in vitamin A and preferred for porridge and Nsima[3] and groundnuts variety like *Chalimbana 2003*. In the Mzimba district, the establishment of CSBs was supported by a local organization called FOCUS, focusing on multiplying, and storing local varieties of maize (*Lokolo* and *Kafula wa yellow*) and improved groundnut variety *CG7*. Crops and varieties available in these CSBs depend on farmers' demands and preferences, and we focus mainly on maize, groundnuts and soyabean. Table A in the supplementary materials provide a short description of the attributes of some of the varieties available in these CSBs. These CSBs offer access to not only seeds but also infrastructure (seed storage room) and technical support (training). Traditional storage structures like grass thatched housing for bulk seed storage and airtight glass jars to store healthy seeds are some of the seed storage practices. Formulation of these CSBs involves open membership. The initial introduction of these CSBs to a community involves NGOs with support from agricultural extension workers and permission from local community leaders, calls for a community meeting where a broader concept of CSBs is introduced and allows willing farmers to form groups, select crops and varieties to store, select leadership for the group and create their own rules of managing the groups. The NGOs then give support with seed management training and even, in some cases, the construction of seed storage buildings. Each CSB has its bylaws, which include membership fee, seed repayment schedule, rules for sharing seeds, rules governing group activities (group meetings, group work), vetting criteria for new members, selection criteria for the executive committee, and punishment rules for violators (seed defaulters). One of the rules in observing seed quality is that the committee members inspect the quality of seeds received and distributed while keeping records of the quantity borrowed and repaid. Once a farmer becomes a member of a CSB and pays the membership fee, which can vary between different CSBs, they gain access to seeds. Membership fees vary from 1000 Malawi kwacha to 3000 Malawi kwacha.[4] The membership fee is paid annually. Membership numbers vary in these CSBs, with some CSBs showing an increase in membership while others show a decline in membership (see Table B in the supplementary materials). CSB membership means one member per household (Meixner Vásquez and Andersen, 2023). One possible reason why some CSBs show a decline in membership in the country is the support change, e.g., withdrawal of support from NGOs.

We used a stratified random sampling technique to select 688 farming households in the five districts. Out of the sampled households, 450 (65 %) of the sample were participants of CSBs, while 238 (35 %) of the sample were non-participants (Table 1). When possible, we interviewed both the household head and the spouse in each household to obtain complete information. We collected data on farmers' participation in CSBs and household information like demographics, agricultural production, food security indicators, seed preference, and seed sources.

Table 1
Summary statistics of sampled farm households.

	CSB (n = 450)		Non-CSB (n = 238)		Pooled (n = 688)	
	Mean	SD	Mean	SD	Mean	SD
Age (Years)	49.88	14.30	45.57	14.94	48.39	14.66
Education (Years)	6.37	3.76	5.14	3.82	5.95	3.82
Household size	5.01	1.92	4.26	1.59	4.75	1.85
Land size (acres)	3.58	3.0	2.13	1.48	3.37	3.08
Maize (1 = yes)	0.98		0.99		0.98	
Groundnut (1 = yes)	0.61		0.30		0.51	
Soyabean (1 = yes)	0.66		0.50		0.61	

Source: Own survey data based on farmers responses.

Table 1 provides a socioeconomic description of the sampled farm households. We focused on three crops: maize (grown by 98 % of the sampled households), groundnuts (51 %), and soyabean (61 %). We included maize in the analysis because it is an important food crop in the Malawian food system, and it is also interesting because it is the crop that receives most formal sector investments and subsidies. Groundnuts and soyabeans are included because they also contribute substantially to the household's food basket and agricultural income, but in contrast to maize, the formal seed system channels offer a limited share of the seeds used. These crops are also available in CSBs. On average, the sampled households had land sizes of about 3 acres, household heads attained at least basic primary education, and households had an average household size of 5 members (Table 1). We also complement this household survey data with historical monthly rainfall and average temperature data covering the period 2010 to 2018 from WorldClim[5] (Fick and Hijmans, 2017) gathered using georeferenced locations for the households included in the survey. Data cleaning and analysis were done using Stata 17 software.[6]

3.2. Estimation strategy

We assume that smallholder farmers' decisions to participate in CSBs are driven by perceived benefits from participation, such as access to seeds contributing to crop yields and food security outcomes. In other words, participation occurs when the expected utility (benefit) from participation (P_1) exceeds that of not participating (P_0). The expected utility gain from participating in a CSB ($P^* = P_1 - P_0$) can be expressed as a function of observable and unobservable covariates (X) as in Eq. (1):

$$P_j^* = \theta X_j + \alpha_j, P_j = 1 if P_j^* > 0, \quad (1)$$

where P_j is a binary variable that takes a value of 1 if a farmer is a participant and decides to source seeds from CSBs and zero otherwise. θ is a vector of parameters to be estimated, and X is the vector of control variables (household, farm characteristics, socioeconomic, environmental, and seed source characteristics variables), and α is a normally distributed random error term. Participation in CSBs is hypothesized to contribute to crop yield and food security, as explained in the conceptual framework. In this analysis, we use several crop yield outcomes (maize yield, groundnut yield, and soyabean yield in kgs/acre), and we proxy household food security using subjective measures of household food insecurity, as explained in detail in section 3.3. If we assume that household crop yield and household food security measures (Q_j) can be expressed as a linear function of a vector of exogenous control variables (V_j) and the endogenous decision made by farmers to join CSB (P_j) we can express the relationship between Q_j, P_j, and V_j as in Eq. (2):

$$Q_j = \vartheta V_j + \omega P_j + \tau_j \quad (2)$$

[3] Nsima is a local dish made from maize flour.

[4] Exchange rate of 1 USD to 1735 Malawi Kwach at 2024 exchange rate.

[5] https://www.worldclim.org/data/monthlywth.html.

[6] StataCorp, 2021. Stata statistical software release 17. College Station, TX. StataCorp LLC.

where, Q_j are household crop yield and food security outcomes, V_j and P_j are respectively control variables for crop yield, food security outcomes, and CSB participation. ϑ, and ω are parameters to be estimated, and τ is the error term.

We rely on a cross-sectional data set including both CSB participants and control (non-participants), where assignment into the two groups cannot be assumed to be purely random. Hence, it is possible that food security outcomes of CSB participants and non-participants are systematically different due to a possible self-selection bias associated with participation (Smith and Todd, 2005). Selection bias is explained as the systematic differences in either observable or unobservable factors that can influence the conditions of participation. For instance, it might be the case that farm households that are resource-constrained are motivated to join CSBs to access seeds, while better-off farm households may not see the benefits of participation. The other way around can be that the farmers with larger farms need more seeds and are more likely to join CSBs as they are more production-oriented.

The implication of this potential self-selection bias is that estimating Equation (2) using Ordinary Least Squares (OLS) regression might lead to biased estimates. Hence, we use Propensity Score Matching (PSM) to estimate the treatment effects of participation in CSBs. PSM is a nonparametric approach widely used in estimating treatment effects (Caliendo and Kopeinig, 2008), and a large body of studies in the agricultural development economics literature has relied on the approach to control for self-selection bias in estimating treatment effects of various agricultural decisions (Amare et al., 2012; Faltermeier and Abdulai, 2009; Makate et al., 2017; Mapila et al., 2012; Matchaya and Perotin, 2013). The PSM method identifies causal effects under two primary assumptions: the conditional independence assumption and the overlap assumption. The conditional independence assumption says that observable characteristics must be independent of potential outcomes, which implies that the decision to join a CSB is based on observable household characteristics (Imbens, 2004). Conversely, the overlap assumption (common support condition) requires the existence of appropriate overlaps in the characteristics of the treatment group and non-treatment group and requires that the distribution of propensity scores between CSB participants and non-participants should overlap.

We employ PSM at two levels in our analysis. First, in the plot-level yield PSM, the treatment variable is whether seeds from CSBs were utilized on a particular plot. Plot-level analysis allows us to control for critical factors influencing crop productivity, such as soil quality, slope, rainfall, and input management on that same plot. Secondly, in the household-level food security PSM, the treatment is again CSB participation, while the control variables are various household and farm-level characteristics. We apply this dual-level propensity matching approach to account for potential confounding factors and provide a more accurate assessment of the association of CSB participation with both plot and household-level outcomes. However, our data is not detailed enough to include the unobservable behavior factors in the analysis, like farmers' motivations, risk, and trust behaviors. Additionally, our data does not capture changes in seed-sourcing decisions over time as we rely on cross-sectional data.

In our implementation of PSM, we first regress a dummy variable of participation in CSBs (P) on a set of household observable variables (X), using a probit regression to obtain propensity scores of participations (Hirano et al., 2003; Lee et al., 2011) as shown in Equation (1). The resultant propensity scores ($PS_j = prob(P_j = 1|X_j)$ represent the probability that a farmer belongs to a CSB (or uses seed from a CSB on a particular plot), with the marginal effects on the selected covariates (X) indicating the direction of association of these variables with the probability of participation (See Table 7).

After generating the propensity scores, we proceed to match CSB participants to non-participants using the Nearest Neighbor Matching (NNM) and Kernel Matching (KM) techniques, along with the Radius Matching (RM) technique, as a robustness check. The use of more than one matching technique is recommended, given that PSM methods are sensitive to specification and matching method choice (Caliendo and Kopeinig, 2008; Imbens, 2004). The NNM technique matches each CSB participant to a non-participant based on the closeness of the propensity scores, while the KM involves matching CSB participants with a weighted average of non-participants using weights inversely proportional to the distance between their propensity scores (Dehejia and Wahba, 2002; Imbens, 2004). In addition, RM considers all comparison observations (CSB and non-CSB participants) within a predefined distance around the propensity score (radius) (Becker and Ichino, 2002; Dehejia and Wahba, 2002; Imbens, 2004). The advantage of RM over the NNM method is that it offers more flexibility by allowing matches within a specified distance (radius), even if they are not the closest, which can improve match quality.

Once matching is completed, we check for the extent of the overall covariate balance and overlap of the common support condition. After realizing that we have enough observation within the common support region (Fig. B in the supplementary materials), we proceed to estimate the treatment effects. As a step further to ensure the quality of results, we conducted a covariates balance propensity scores test presented in the supplementary material Table C. As shown in Table C, results indicate a significant reduction in differences in covariate means between participants and non-participants post-matching, confirming satisfactory matching effectiveness.

With PSM, we estimate the Average Treatment Effect on the Treated (ATT), which is considered a better indicator for measuring the appropriateness of interventions in smallholder groups of interest, such as smallholder farmers, than the population-wide Average Treatment Effects (ATE) (Heckman et al., 1998; Imbens, 2004; Rosenbaum, 2002; Rosenbaum & Rubin, 1983). We estimate ATT as in Eq. (3):

$$ATT(X) = E[Q_1|P = 1, prob(X)] - E[Q_0|P = 1, prob(X)], \tag{3}$$

where Q_1, and Q_0 are respectively outcomes (crop yield and food security indicators) for CSB participants and non-CSB participants, and (P) defines participation status in CSBs as previously stated.

Additionally, to ensure the robustness of our findings, we conduct further analysis. We check the robustness of the contribution of CSB seeds to plot-level crop yield by applying a fixed effects model using household plot panel data for the subsample of CSB participants that use a combination of seed sources (including off-farm seed sources). In the household fixed effect model (Table D in the supplementary materials), we observed the significance of yields in the plots where farmers source seeds from CSBs and control for inputs (seed variety, land, fertilizer), observed land quality, using variables for plot attributes (soil type, soil quality, and soil erosion) and variables for household fixed effects. Further, we assess the robustness of our PSM findings by computing Rosenbaum bounds (DiPrete & Gangl, 2004; Rosenbaum, 2002) for ATT to assess the potential influence of unobserved heterogeneity on the results. This method helps us evaluate how sensitive our results are to unobserved heterogeneity and determine the extent to which unobserved factors could affect the reliability of our findings. Our results from this exercise indicate that the PSM results are robust to household-level unobserved biases (see Tables E, F, G, H, I in Supplementary Material).

3.3. Variables included in the model

Table 2 presents the description of the variables used in the model, both explanatory and dependent variables, their measurements, and expected signs. The treatment variable used in the analysis is the dichotomous variable participation in CSBs. Hence, one must be a member to access seeds from these seed clubs. By participating, we mean farmers who accessed seeds from CSBs in the 2021/2022 agricultural growing season and used them in their farm production. Crop yield is measured as kg per acre. Since the study used cross-sectional data, past

Table 2
Description of variables used in the model.

Variable	Description of the variables	Measurement	Expected signs
Explanatory variables			
Socioeconomic	**Variables**		
Age	Age of the household head	Years	+/-
Household size	Number of household members	Number	+
Extension service	Access to extension	1 = Yes	+/-
Sex	Sex of the household head	1 = Female	+/-
Education	Highest education attained	Years	+/-
Asset wealth index	Farm households' assets	PCA	+
Land Size	**Variables**		
Smaller farm size (quintile 1)	Land size in quintile	Acres	+
Larger farm size (quintile 3)	Land size in quintile	Acres	+
Location	**District dummy variables**		
D1	District dummy (1 = Rumphi)		+/-
D2	District dummy (1 = Mzimba)		+/-
D3	District dummy (1 = Kasungu)		+/-
D4	District dummy (1 = Dowa)		+/-
D5	District dummy (1 = Mchinji)		+/-
Climatic	**Variables**		
Mean Rainfall	Average rainfall (2010–18)	Millimeters	+
Mean Temperature	Average temperature (2010–18)	Degrees	+
Rainfall shortage	Exposure to drought for the past five years (1 = yes)		+
Seed system characteristics	**Variables**		
Distance to the main market	GPS measured	Km	+
Formal[a] market seed share	The proportion of certified seeds purchased from the formal market measured in terms of the total seed	Share	−
AIP seeds	Quantity of subsidized seed	Quantity	−
Other inputs	Fertilizer quantity	Log	+
Seed variety type	Dummy (1 = improved)		+
Plot level attributes	**Variables**		
Plot soil quality dummy	Soil quality (1 = Good)		+
Plot soil quality dummy	Soil quality (1 = poor)		−
Plot soil type	Soil type dummy		+/-
Plot soil erosion dummy	Soil erosion (1 = No)		+
Outcome variables			
Participation in CSB	Binary (the household has a member of CSB)	1 = Yes	
Plots with CSB seeds	Binary (plots with CSB seeds)	1 = Yes	
Maize yield	Kg per acre	log	
Groundnut yield	Kg per acre	log	
Soyabean yield	Kg per acre	log	
Probability of food insecurity in the past 12 months	Probability of not having enough food for the household in the past 12 months	1 = Yes	
Food insecurity access score	Number of food insecure months in the past 12 months	Months	
Food insecurity access score	Number of food secure days in the past seven days	Days	

[a] The Formal market comprises of seeds sourced from the town markets where seed companies are located and Agrodealer who supply certified seed and ADMARC.

participation was not regarded as participation in this study if the farmer did not access seeds from CSB for the 2021/2022 agricultural growing season.

Measuring food insecurity is complex as it covers a wide range of multi-dimensional aspects, and no single indicator can capture all dimensions of food security (Jones et al., 2013). As such, capturing household food insecurity indicators allows some levels of subjectivity on the sufficient food bundle to meet individual and household needs. We used experiential measures of food insecurity in the access domain. The probability of food insecurity in the past 12 months is measured as a dichotomous variable representing whether the household participants were food insecure. We also include the food insecurity access score measured as the number of (hunger) months in the past 12 months and the past seven days the household worried about not having enough food. We used both short-term recall (past seven days) and long-term food access (past 12 months) to capture variations in food access. See Table J in supplementary material on how the questions capturing household food insecurity were framed. A summary of crop yield and food security outcomes is provided in Fig. C in the supplementary materials.

We used standard control variables from the agricultural development/economics literature that explain participation in farmer groups and technology adoption (Amponsah et al., 2023; Dawuni et al., 2021; Liu et al., 2021). Principle component analysis (PCA) using agricultural farm assets was used to calculate asset or wealth status. The component variables used in the PCA include variables that define household farm assets, equipment, and structures.[7] Another variable we included in the model is the land size quintile. The land size quintile allowed us to disaggregate larger farm sizes, middle farm sizes, and small farm sizes. We generate quintiles of farm size using the total holding of the households in the sample, and average farm sizes (in acres) for the lowest, medium, and largest quintiles are 1.2, 2.5, and 6.4 acres, respectively (see Fig. D in supplementary material). As a robustness check, we ran the analysis with plot size in acres as a continuous variable to see if results were affected when we used quintiles of land size, and the results did not alter the conclusions from the correlations we report in the paper (see Table K and L in the supplementary materials). We used the winsorization procedure (5 %) to deal with outliers in our data and maintain the original sample size. Multiple studies have used this approach to avoid loss of information (Dixon & Tukey, 1968; Wilcox, 2011; Xao et al., 2014).

In addition to socioeconomic and institutional variables, we include seed system characteristics variables. In the analysis, we include several seed sources from which farmers get seeds off-farm. In the context of Malawi, subsidized inputs play an important role in farmers accessing certified seeds at an affordable price; hence, we included the quantity of seed sourced from input subsidy (AIP) as one factor that can influence farmers' participation in CSBs. Additionally, we included the degree of farmer's participation in formal markets, calculated as the share of seeds sourced (in weight) from formal markets out of the total volume of seeds used. To provide a comprehensive assessment of the association between participation in CSBs and crop yield, we included variables for plot attributes like soil quality, soil type, and soil erosion, in addition to fertilizer use per plot and seed variety type as control variables. We relied on farmers' stated plot attributes and characteristics. As for plot size, we utilized GPS to measure plots, and in cases where we failed to measure,

[7] The full list of farm assets, equipment, and structure used to compute the asset status are hand hoes, slashers, axe, sprayers, panga knife, sickles, treadle pumps, watering can, ox carts, ox plough, tractors, ridger, cultivators, generator, motorized pump, grain mill, granary, livestock kraal, and barn.

we relied on self-reported plot size. The reasons for not measuring all plots were poor network coverage and bad weather.

On climatic variables, we used rainfall, temperature, and exposure to rainfall shortages as climate-related variables. We build measures of rainfall, average temperature conditions, and average exposure to rainfall shortages in the recent past (average exposure in five years (growing seasons) before the survey) during the main crop growing season (November to April). We define average rainfall (mm) as the average rainfall received during the growing season (November-April) from 2010 to 2018 (see Fig. E in the supplementary materials). We build a measure of average temperature conditions during the season (November-April) as the average (Maximum + minimum)/2) temperature for the period 2010–2018. We also construct a proxy for rainfall shock (drought) exposure in studied areas. We first define lagged rainfall shocks as normalized standard deviations of rainfall during the growing season from a reference period (average conditions for 2010–2018). Hence, a lagged rainfall shock is defined as $Rs_{it} = \left[\frac{Rain_{it} - \overline{Rain_i}}{\sigma_{Rain_i}}\right]$, where Rs_{it} is a rainfall shock measure for a household (i) in the year (t), $Rain_{it}$ is the observed amount of rainfall for the defined period (the growing season from November to April), $\overline{Rain_i}$ is the average seasonal rainfall for the household (i) over the reference period (2010–2018), and σ_{Rain_i} is the corresponding standard deviation of rainfall during the same period. To do this, we calculate the average normalized rainfall deviations for each household over the five seasons prior to 2019/20 (from 2014/15 to 2018/19). Households with a negative average normalized rainfall deviation over this period are classified as those that have experienced a rainfall shortage, indicated by a binary variable where a value of one represents a rainfall shortage experience and zero otherwise.

By including these measures of climate conditions in our analysis, we aim to control for potential omitted variable bias and examine whether past exposure to rainfall shortages is correlated with participation in CSBs. We add measures of average climatic conditions in our analysis to control and reduce omitted variable bias and test whether past exposure to rainfall shortage correlates with participation in CSBs. Fig. F, in the supplementary materials, shows the distribution of climate variables (rainfall and average temperature) included in the analysis. We do not have information indicating whether exposure to climatic shocks has been part of the targeting by the NGOs supporting the CSBs, and we acknowledge this potential confounding factor in our analysis.

4. Results and Discussion

4.1. CSBs and seed sourcing

We start by presenting an overview of the smallholder farmer’s seed sources and the use of CSBs. Table 3 presents the share (%) of seeds by source, measured as the quantity (kg) of seeds acquired from each source divided by the total quantity of seeds planted per crop. We categorize the seed sources as follows. We define the formal market to comprise seeds purchased from the main market, agrodealer, and ADMARC, while the informal seed market comprises seeds purchased from local markets, fellow farmers and mobile markets. We categorize developmental support as certified seeds given as gifts or emergency relief, while social networks comprise seeds sourced from relatives and fellow farmers with non-monetary transactions, e.g. gifts or exchanges. We observe that for all crops (maize, soyabean, and groundnuts), the most utilized source (54 %) of seeds for non-participants is farm-saved seeds, while they purchase about 30 % of all seeds from formal and informal markets vendors (about 15 % from each type). Our results agree with the 30 % purchased seed figure reported for Malawi in Makate et al. (2023) based on a nationally representative panel dataset covering three survey rounds from 2010 to 2020. Among CSB participants, the bulk of seeds for maize, soyabean, and groundnuts are sourced from CSBs (37 %). The same was observed when we disaggregated per crop. This shows that CSB is a major seed source for the CSB participants, while the overall share of farm-saved seed is more than 20 % lower among participants than for non-participants. It is also interesting to note that the share of subsidized seeds is low for both CSB participants and non-participants. Changes in political and economic structure, especially through AIP, also affect access, availability, and even affordability of seeds by smallholder farmers who are highly influenced by policies through information and economic incentives (Holden, 2018). For instance, in the 2021/2022 agricultural growing season, the subsidized maize seed package (5 kg) redeeming price increased from MK4000 to MK8000. Such an increase in redeeming price is a constraint to smallholder farmers, limiting their access to certified seeds. This is one of the possible reasons for the low percentage of seeds sourced from AIP in our data.

4.2. Participation in CSBs and livelihood outcomes

Here, we link participation in CSBs to crop yields and food security outcomes. Starting from a descriptive comparison of participants with non-participants (Table 4), we see that CSB participants have a higher crop yield compared to non-participants for all crops and have slightly better food security outcomes. For instance, on average, non-CSB participants experience 0.49 more months with limited food than CSB participants. Also, non-CSB participants have a lower food insecurity access score and a 12 % higher chance of not having had enough food in the past seven days of the study. The difference is statistically significant. However, household and farm characteristics like household size,

Table 3
Overview of sources of seeds as share (%) of seed per .

	All crops		Maize		Groundnuts		Soyabean	
	CSBs	Non-CSBs	CSBs	Non-CSBs	CSBs	Non-CSBs	CSBs	Non-CSBs
Farm saved	32.1	53.8	29.3	51.0	36.3	62.5	30.3	54.9
Formal[b] Market	10.8	14.9	13.2	17.4	10.3	12.5	16.5	7.5
subsidized seeds	2.6	2.8	5.3	3.3	1.9	4.2	1.4	4.2
Informal[c] Market	10.9	14.9	11.2	13.4	15.1	16.7	13.9	21.7
Development support	1.4	1.7	2.2	2.1	0.7	1.4	1.0	4.2
Social networks	5.7	11.9	6.5	12.7	6.1	2.8	5.3	10.1
CSBs	36.6	0	33.9	0	30.0	0	31.7	0
N	450	238	442	236	276	72	298	120

Source: Own survey data based on farmer’s responses. Share (%) was measured as the quantity (kg) of seeds acquired from each source divided by the total quantity of seeds planted.

[b] The Formal market comprises of seeds sourced from the Main market, Agrodealer, and ADMARC.

[c] The Informal market comprises of seeds sourced from the local markets, relatives, neighbors, community leaders, Mobile markets, NGOs, and cooperatives.

Source. “All crops” comprise maize, groundnuts and soyabean

Table 4
Comparison of CSB and non-CSB participants.

	CSB n = 450	Non-CSB n = 238	*t*-test (p-value)	Full sample n = 688
Months limited food	1.14	1.63	0.00***	1.31
Food_availability (Days out of 7 days of not worried about limited food)	2.41	3.53	0.01***	2.79
Probability of food insecurity last 12 months (1 = yes)	0.19	0.31	0.00***	0.23
Soyabean yield	223.80	136.06	0.00***	193.45
Groundnut yield	244.24	98.22	0.00***	193.73
Maize yield	886.76	720.41	0.01***	829.21
Access to extension	0.97	0.94	0.05**	0.96
Household size	5.01	4.26	0.00***	4.75
Education (Years)	6.37	5.14	0.00***	5.95
Sex (1 = Female)	0.26	0.31	0.14	0.28
Age (Years)	49.88	45.57	0.00***	48.39
Land size (acre)	3.58	2.13	0.00***	3.08
Smaller farm size (quintile 1)	0.23	0.53	0.00***	0.33
Larger farm size (quintile 3)	0.44	0.14	0.00***	0.33
Asset wealth index (PCA)	0.38	−0.71	0.00***	0.00
Distance to main trading center (km)	26.04	22.74	0.01***	24.90
Formal Market share seeds	0.31	0.26	0.25	0.29
AIP quantity (kg)	1.04	0.66	0.20	0.91
CSB share Seed	36.65	0.00	0.00***	24.37

Notes: ***Significant at 1% level; **significant at 5% level; *significant at 10% level.
Source: Own survey data based on farmer's responses.

education, age, land size, distance to the main trading market, and asset-wealth index were also statistically different between participants and non-participants. After observing these differences between CSB participants and non-participants, we take a step beyond comparing subgroup means to address potential associations between participation and productivity and livelihood outcomes using the analytical strategies explained earlier, allowing us to control for potential confounders.

4.2.1. CSBs and plot-level crop yield

In the plot-level PSM analysis, we used plots with seeds sourced from CSBs compared with plots with seeds sourced from other sources. Our dependent variable is a dummy variable indicating plots with CSB seeds, and we controlled for household characteristics and plot characteristics, such as land quality, fertilizer use, and seed variety type (Table 7). Fig. B in the supplementary materials shows that common support was satisfied. Overall, the data covers 1600 plots. In Table 5, we present results from PSM. We report average treatment effects on the treated (ATT) from two matching algorithms, Nearest Neighbour Matching (NNM) and Kernel Matching (KM) methods.

From the results (Table 5), we observe a positive correlation (higher crop yields) between plots with soyabean seeds sourced from CSBs and lower crop yields for maize. We also found a positive correlation but not significant on groundnut yield. Robustness check results for the radius matching method are also significant (Table M in the supplementary materials). If we consider aggregate crop production (at the household level), we observe a positive correlation (higher crop yield) for groundnuts and soyabean with no significant correlation with maize (Table N in the supplementary materials). In Malawi, maize is one of the staple crops, highly prioritized in the formal seed sector, and is key to food security (Denning et al., 2009; Smale, 1995). The formal maize seed system is more developed in Malawi, and improved maize varieties are accessible from the market and subsidized, potentially explaining why maize plots with CSB seed had lower yields than those without. Another possible explanation for the lower yields on maize plots planted with seeds from CSBs is the use of non-hybrid seed varieties. Although these varieties typically yield less, they are often preferred by farmers for subsistence farming due to their favourable post-harvest characteristics, such as better storage qualities and ease of processing (e.g., poundability) (Vansant et al., 2022; Lunduka et al., 2012). We also remind readers about the caveat that survey data like ours do not allow us to distinguish between the effects of varietal quality (their adaptation to local agroecological conditions an end uses) and aspects of seed quality (e.g. seed viability, vigor, physical purity).

4.2.2. CSBs and household food security outcomes

We further assess the potential association between participation in CSBs and household food security outcomes (Table 6). Participation in CSBs is significantly associated with reduced household food insecurity, as measured by three indicators (Table 6). Precisely, participation in CSBs is associated with a reduction in household food insecurity access score with 0.58–0.73 days out of 7, months with limited food with 0.11–0.16 months out of 12, and the probability of being food insecure during the last 12 months by about 10 %.

One potential explanation for the positive associations observed is that having access to a diversity of varieties of legumes and local maize varieties, which do not normally receive much attention from formal seed systems, contributes to diverse foods, nutrition, and income. Also, the correlation between participating in CSBs and household food security outcomes could come from their indirect contributions to food security through enhancing access to social capital (as a community group), which in itself is linked to numerous benefits; for instance, it offers informal insurance to shocks within the community and often facilitates knowledge exchange and capacity building, empowering farmers to adopt sustainable agricultural practices that enhance productivity and food availability. Despite having low maize yields, farmers might prefer other agronomic or consumption traits to high yields for their choice of maize seeds from CSBs.

4.2.3. Correlates of participation in CSBs and use of CSB seeds at plot level

In this section, we discuss the correlations between participating in CSBs and using CSB seeds. Table 7 summarizes the factors associated with the probability of utilizing CSB seeds at the farm plot level (columns 1 and 2) and household participation in CSBs to household food security (columns 3 and 4). The results show that household size, education, location, mean temperature, exposure to rainfall shortages,

Table 5
The correlation of CSB seeds on plot-level crop yield estimates from Propensity Score Matching.

	Maize yield (kg/acre)		*Groundnut yield (kg/acre)*		*Soyabean yield (kg/acre)*	
Variables	NNM	KM	NNM	KM	NNM	KM
ATT	−0.541**	−0.500***	0.156	0.0239	0.272	0.284**
	(0.265)	(0.172)	(0.163)	(0.112)	(0.180)	(0.124)
N (plots per Crop)	772	772	378	378	450	450
CSB	2.10	2.11	1.01	1.01	1.38	1.39
Non-CSB	2.63	2.63	0.88	0.88	1.15	1.15

Notes: ***Significant at 1% level; **significant at 5% level; *significant at 10% level. Standard errors for the Average treatment effects on the treated (ATT) in parentheses are calculated using bootstrapping with 300 replications. Nearest Neighbor Matching (NNM) and Kernel Matching (KM)

Table 6
The correlation of participation in CSBs on household food security.

Variables	Food unavailability (Days out of 7 days)		Months limited Food (Months)		Probability of food insecure last 12 months	
	NNM	KM	NNM	KM	NNM	KM
ATT	−0.579**	−0.732***	−0.157*	−0.108*	−0.096*	−0.079*
	(0.257)	(0.269)	(0.082)	(0.059)	(0.055)	(0.047)
Observations	530	627	627	627	530	627
CSB	1.27	1.18	0.51	0.51	0.223	0.201
Non-CSB	1.63	1.63	0.54	0.54	0.307	0.307

Notes:
*** Significant at 1% level.
** significant at 5% level.
* significant at 10% level. Standard errors for the Average treatment effects on the Treated (ATT) in parentheses are calculated using bootstrapping with 300 replications. Nearest Neighbor Matching (NNM) and Kernel Matching (KM).

fertilizer use, and soil quality significantly correlate with the probability that the household uses seed from CSB at the plot level. For the household-level analysis, where we have household participation in CSBs as the dependent variable, we see that access to extension, education, location, larger farm size, distance to the main trading market, and past rainfall shortage experience positively correlate with the probability of participating in CSBs. Results from the household-level analysis demonstrate a slightly better fit (r-squared = 0.47) and shed light on the factors likely to influence households' decisions to participate in CSBs.

We find strong support for our hypothesis that past exposure to climate shock is associated with the probability of farmer participation in CSBs. This finding is in line with the results from the plot-level analysis, which show that exposure to rainfall shortages positively correlates with the use of CSB seeds at the plot level. This finding could suggest that CSBs are an option for smallholder farmers to adapt to droughts. Putting it into context, the present study and others (Bezabih, 2008; Vernooy et al., 2017) suggest that CSBs can enhance resilience, as proxied by food security indicators, among farmers, especially in communities mostly affected by climate shocks and those that are distant from main trading markets. Therefore, promoting CSBs in such communities can improve farmers' seed access and support adaptation to shocks. We also discuss some of the other significant findings from the household-level analysis as they provide insight into some factors that explain household participation in CSBs.

Access to extension increases the probability of participating in CSBs by about 12 %. Also, households in the top quintile of farm size (large farm size) have about 8 % higher chances of participating in CSBs, while those in the smallest farm size quintile (smaller farm size) have 5 % lower chances of participating in CSBs compared to those in the medium category (medium farm size) (Table 7). In addition, results also show that the probability of participating in CSBs marginally increases with long distance to the main trading market (6 %).

We observe a lower probability of farmers participating in CSB in the Kasungu and Mchinji districts than in the Rumphi district (Table 7). It is worth noting that districts like Kasungu and Mchinji are major agricultural-producing districts in Malawi because they have more arable land with better fertility (Potts, 2006). This influences the presence of agrodealers trading in different areas across districts and facilitates access to improved seeds by farmers at relatively lower transaction costs.

We hypothesized that access to certified seeds sourced from formal markets could reduce the probability of participating in CSBs. However, unlike in earlier studies (Bezabih, 2008), we did not find a statistically significant association with this variable. The same was observed with access to subsidized inputs. One possible explanation is that there was a low (8 %) number of sampled farmers that accessed subsidized input in the study's agricultural year 2021/2022. In the Malawian case, CSBs are a complementary seed source to other seed sources.

5. Conclusion

Our study focused on farmers' use of CSBs as a seed source, the association of participating in CSBs on crop yields, household food security status, and the potential role of past exposure to climate shock in influencing participation in CSBs. We were guided by three research questions. First, we aimed to answer the question of how much farmers are using CSBs as a seed source. We found that for participants, a large share (37 %) of seeds for maize, groundnuts, and soyabean are sourced from CSBs. Thus, CSBs are a salient complementary seed source for those participating. The second research question was whether participation in CSBs is associated with higher crop yields and less household food insecurity. We found that utilizing seeds from CSBs is positively associated with higher soybean yield but lower maize yields and that participation in CSBs is associated with reduced household food insecurity. The lower yield on maize plots planted with seeds from CSB is possibly due to relatively lower-yielding seeds of the varieties available from CSBs, but such varieties are often still preferred for their post-harvest characteristics. Our third and last research question was about the association between exposure to climate shocks and participation in CSBs. We found that exposure to high historical mean temperature and past exposure (experience) to rainfall shortages correlates with farmers participating in CSBs. This suggests that participating in CSBs is used as a strategy for adaptation to climate risks.

In conclusion, this study has shown that CSBs can be an important source of seeds for participating farmers and that participation is positively associated with higher yields for some crops as well as lower levels of household food insecurity. Further research using panel data and experimental approaches is needed to probe the causal mechanisms between participation and yield and food security outcomes. Such studies should also be designed in ways that enable distinguishing between the relative effects of varietal quality vs. seed quality. Since CSBs are rather small and localized institutions, issues of scale and economic sustainability remain important elements of the future research agenda. Related to this is the question of the opportunity cost of investing in CSBs vis-à-vis other approaches to strengthen farmers' access to quality seeds.

6. Policy implications

Community Seed Banks is an institutional innovation in seed system development that has gained considerable traction around the world over the last decade (Vernooy et al., 2024). While CSBs can have multiple functions and objectives, all share the objective of making seeds of farmer-preferred varieties accessible to farmers. As such, CSBs are set up to be alternatives or complements to conventional seed distribution institutions in the formal seed system. CSBs are often called "intermediary" seed system organizations because they combine elements of the formal (specialized off-farm seed production) with elements of the informal seed systems (farmer-to-farmer dissemination of seeds) and because they often also serve as platforms for bringing breeders and

Table 7
Probit regression estimates for the probability of using CSB seeds (Plot-level) and household participation in CSBs (Household level).

	Plot-level		Household-level	
	(1)	(2)	(3)	(4)
	Coefficients	Marginal effects	Coefficients	Marginal effects
Variables	b/se	b/se	b/se	b/se
Access to extension (1 = yes)	−0.193	−0.053	0.640*	0.127*
	(0.202)	(0.056)	(0.384)	(0.078)
Household size	0.040*	0.011*	0.034	0.007
	(0.021)	(0.006)	(0.040)	(0.008)
Education (Years in school)	0.021*	0.006**	0.043**	0.008**
	(0.011)	(0.003)	(0.020)	(0.004)
The household head is female (1 = yes)	0.074	0.020	−0.143	−0.029
	(0.089)	(0.025)	(0.166)	(0.034)
Age of household head (Years)	−0.014	−0.004	0.001	0.000
	(0.017)	(0.005)	(0.030)	(0.006)
Age of household head squared/10	0.002	0.001	0.001	0.000
	(0.002)	(0.000)	(0.003)	(0.001)
Smaller farm size (quintile 1)	−0.060	−0.017	−0.277*	−0.055*
	(0.091)	(0.025)	(0.151)	(0.029)
Larger farm size (quintile 3)	−0.000	−0.017	0.444**	0.088**
	(0.090)	(0.025)	(0.180)	(0.036)
Rumphi district	0.678***	0.188***	0.855*	0.170*
	(0.182)	(0.050)	(0.508)	(0.098)
Kasungu district	−0.094	−0.045	−0.647*	−0.129*
	(0.187)	(0.052)	(0.383)	(0.075)
Dowa district	0.568***	0.157***	−0.591*	−0.118*
	(0.163)	(0.044)	(0.312)	(0.063)
Mchinji district	0.024	0.007	−0.955***	−0.190***
	(0.172)	(0.048)	(0.304)	(0.057)
Log distance to the main trading center (km)	−0.104	−0.029	0.369**	0.073**
	(0.073)	(0.020)	(0.161)	(0.031)
Asset wealth index (PCA)	0.008	0.002	0.063	0.013
	(0.021)	(0.006)	(0.046)	(0.009)
Mean rainfall (2010–18) (log)	−0.083	−0.023	−3.353*	−0.668*
	(0.979)	(0.274)	(1.966)	(0.386)
Mean temperature (2010–18) (log)	4.644***	1.286***	2.542	0.506
	(1.213)	(0.332)	(3.058)	(0.596)
Rainfall shortages (past five years)	0.328***	0.091***	0.318**	0.063**
	(0.087)	(0.024)	(0.142)	(0.029)
Formal Market seeds share (%)			−0.079	−0.016
			(0.159)	(0.032)
Subsidized seeds (Kg)			0.025	0.005
			(0.018)	(0.004)
Soil quality dummy (1 = Good)	0.219**	0.061**		
	(0.089)	(0.025)		
Soil quality dummy (1 = Moderate)	0.161	0.045		
	(0.136)	(0.038)		
Soil type dummy (1 = sandy)	0.180	0.050		
	(0.114)	(0.032)		
Soil type dummy (1 = sandy + clay)	0.007	0.002		
	(0.100)	(0.028)		
Soil type dummy (1 = clay)	0.016	0.005		
	(0.112)	(0.031)		
Plot soil erosion dummy (1=No)	0.079	0.022		
	(0.080)	(0.022)		
Seed Variety (1 = improved)	0.288***	0.080***		
	(0.101)	(0.028)		
Fertilizer quantity (log)	−0.062***	−0.017***		
	(0.017)	(0.005)		
N-plots (households)	1600	1600	688	688
Ll	−789.8		−235.0	
r2_p	0.0935		0.470	

Notes:
*** Significant at 1% level.
** significant at 5% level.
* significant at 10% level. All estimates are based on robust standard errors. Standard errors are in parentheses.

other seed system professionals together with farmers. FAO's voluntary guidelines for national seed policy formulation (FAO, 2015) explicitly mention CSBs and other community-based seed production groups as a new type of seed sector actor that governments should consider including in their seed policies. The African Union and some African governments (Ethiopia and Uganda) have already endorsed Integrated Seed System Development policies providing legal space to operate for intermediary seed system organizations like CSBs (AU, 2011; MoA 2017; MAAIF 2018). Other African governments, like the Malawian, have opted for conventional seed system development policies focusing on the formal sector as reflected in the National Seed Act of 2022 (Malawi Government 2022), but remain tolerant of the existence of CSBs and other intermediate and informal seed system practices.

Formal recognition of CSBs as a seed system actor in national policy and law could have some sustainability benefits. Formal recognition could allow for officially recognized quality control of the seeds distributed, such as Quality Declared Seed (QDS) or similar appropriate seed classification (FAO, 2006). This is, in most countries, a prerequisite for commercial sale and distribution of the seeds produced. Another common requirement for commercial seed distribution is variety registration, and CSBs today qualify to register farmers' varieties in some countries (De Jonge et al., 2025). Other sustainability strategies identified by Vernooy et al (2024) are about establishing networks with other CSBs as well as partnerships with national gene banks. Addressing such policy, legal, technical, and organizational sustainability issues will be important to realize the potential of CSBs in strengthening farmers' seed and food security at scale and over the long term.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodpol.2025.102860.

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