Okori et al. Agriculture & Food Security (2022) 11:38
https://doi.org/10.1186/s40066-022-00375-4

Agriculture & Food Security

RESEARCH Open Access

Improving efficiency of knowledge and technology diffusion using community seed banks and farmer-to-farmer extension: experiences from Malawi

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Abstract

Background: Agri-innovations are mostly delivered to farmers through private and public sector-led institutions around the world, with various degrees of success in Malawi. These distribution systems, on the other hand, do not meet everyone's production and productivity needs, particularly those of smallholder farmers. Alternative gap-filling systems are therefore required. Over the course of 7 years, we performed two studies in Malawi to assess the efficiency of integrated farmer led agri-innovation delivery mechanisms, in order to advise programming and delivery improvements. The first study looked at the impact of farmer-led technology delivery on agricultural output and productivity. It was split into two phases: learning (2010–2015) and scaling-out (2016–2019). The second study looked at how smallholder farmers changed their behaviour, after receiving instruction during the scaling-out phase. A farmer-led social network, community seed banks, was used as the research platform.

Results: The number of farmers who had access to improved seed increased by 35-fold from 2.4% in the baseline year. Groundnut, the major study crop, had a 1.8-fold increase in productivity. In sorghum, and common bean, the difference in grain yield between beneficiaries and control populations was 19% and 30%, respectively. The lowest aflatoxin contamination was found in groundnut grain samples from trained farmers, showing that learning had occurred, with three training sessions sufficient for initiating and sustaining adoption of agri-innovations.

Conclusions: Many developing country economies have limited investments in agricultural extension and advisory services, and as well as inefficient agri-input delivery systems, limiting access to science solutions needed to boost productivity. The farmer-led technology and knowledge dissemination systems examined in this research, are appropriate for a variety farming contexts, especially for crops underinvested by private sector, and where public extension and advisory services are poorly funded.

Keywords: Agri-innovations, Cereals, Extension-service, Farmer led, Knowledge, Legumes, Informal seed systems

Introduction

The goal of many sub-Saharan African (SSA) countries is to catalyse agriculture productivity growth in order to ensure food, nutrition and income security of their populations. This ambition, however, is hampered by

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the restricted availability and use of innovative agricultural inputs [1–3]. Smallholder farmers, particularly marginalized groups of women and youth [4, 5], account for 52% of the workforce in Malawi [6]. These marginalized groups' gender-differentiated rights, have an impact on their long-term land productivity investments [7], and should be handled in an inclusive manner, to secure livelihoods and expand economies [8]. Farming systems supporting such marginalized populations, often involve crop species that have limited propriety control, and therefore, are not attractive for private sector investment [9].

Legumes and cereals, (with exception of maize), are essential components of Malawi's and many SSA agri-food systems, whose seed systems are underinvested by the private sector, [10, 11]. Only 2.4–17% of legume and other self-pollinated crop certified seed is delivered to smallholders in developing countries by private sector [9]. Where governments use subsidies to increase technology access, such as Malawi's Affordable Inputs Programme, the focus is on inorganic fertilizers and main staples like maize, crowding out several food and nutrition security crops [12, 13]. Crop diversification by smallholder farmers in Malawi, however, is based on underinvested crops to meet to food, income and nutrition needs [14–16]. Examples of underinvested crops produced by smallholder farmers of Malawi and many SSA countries include: groundnut (*Arachis hypogea*), pigeon pea (*Cajanus cajan*), common bean (*Phaseolus vulgaris*), sorghum (*Sorghum bicolor*), finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*) [17–19].

Many underinvested crops have lower adoption rates in SSA than in Asia and South America [9, 17, 20]. Improved groundnut adoption rates in Tanzania is 19% [17], about half of what is observed in Malawi, particularly for modern varieties [21]. Farmers who want to obtain improved varieties, are even more limited in options, due to the limited variety portfolio supported by agricultural input delivery agencies. Improved groundnut varieties such as Chitala, Kakoma, Baka and Chalimbana 2005, collectively occupy less than 10% of total area planted to groundnut in Malawi. This is three to five times less than the area under the relatively more popular groundnut varieties, Nsingiro and CG7, which occupy 31.4 and 54.2%, respectively, of area under improved varieties [21, 22]. The underinvested groundnut varieties, on the other hand, have unique production and market qualities such as: early maturity (90–110 days), multiple cropping ability, have good consumption characteristics, which are the foundations for robust agri-food systems. Smallholders who grow underinvested crops, commonly use farm-saved seed, which they replant for several generations, resulting in significantly lower yields of between 50 and 70% and poor quality [23–25]. Given the importance of smallholder farmers for Africa's food security [3], and the fact that they are already progressively intensifying their production, particularly of cereals [12], it is critical to strengthen their seed security by exploring alternative but inclusive seed delivery methods.

In this article, we also looked at farmer-led inclusive ways for expanding smallholder farmers' access to knowledge because of its pivotal role in growing farm productivity. While smallholder farmers appreciate the importance of technology and knowledge in increasing productivity, their aspirations are hampered by poor and dysfunctional delivery systems [26, 27]. Ethiopia's Agriculture Growth Programme, probably one of SSA's productive investments, demonstrates how effective technology and knowledge delivery can empower smallholder farmers to progressively expand their farming operations [28]. Malawi's agriculture extension and advisory services, have a limited scope and scale of operations, which is exacerbated by underfunding [29], and bias toward maize, the staple food, and tobacco the main cash crop [29, 30]. Such a system, disempowers smallholder farmers [31]. Underpinned by social networks or farmer-to-farmer systems [32], inclusive technology and knowledge delivery, can improve the reach-out to under-resourced farming communities [33]. Using two integrated studies, this article assessed the effectiveness of farmer-led technology and knowledge delivery systems among Malawi's smallholder farming communities, in order to influence future programming. The research focused on smallholders farming the legumes: groundnut, pigeon pea, common bean, and the cereals: pearl millet and rice (*Oryza sativa*), in 12 districts across the country. To leverage their collective capacities, farmers were organized via social networks. The study findings are examined in relation to the design of technology and knowledge scaling-out investments to under-resourced farmers in rural communities of Malawi.

Methodology

Conceptual framework

The effectiveness of farmer-led systems for boosting access to productivity-enhancing technology, and knowledge by smallholder farmers, in order to unlock value from agriculture for their livelihood needs, is presented and discussed in this article. The effectiveness of farmer-led technology and knowledge delivery systems among smallholder farmers of Malawi was investigated using two integrated studies that focused on two important segments of agricultural value chains. The first study, looked into the effectiveness of farmer-led technology delivery systems on the production segment of crop value chains. This research was split into two parts: a learning phase that lasted five cropping seasons (2010–2011 to 2014–2015), and a scaling-out phase that lasted three cropping seasons (2016–2017 to 2018–2019). The second study looked at how farmer-led knowledge delivery systems affected behavioural changes in smallholder farming techniques. Both studies used Community Seed Banks (CSBs), an informal farmer led social network mechanism, that improveds access to seed by leveraging collective operations in rural communities. The CSBs help under-resourced rural farmers produce, store and deliver/access planting material [34, 35]. The treatment cohort consisted of CSB members who received research interventions, while the control cohort consisted of non-CSB members, who had not interacted with the research. Farmer-led agriculture extension and advisory service access were also supported by the CSBs, which used trained lead-farmers[1] to implement farmer-to-farmer extension. Professionals instructed and gave learning materials to lead-farmers, for training fellow farmers. Farmer-led methods are appropriate for low-cost agricultural extension and advisory services [36]. Learning was measured by looking at how people changed their behaviour after being exposed to good agronomic practices, the detrimental impacts of aflatoxins[2] and effective solutions for mitigating aflatoxin contamination of grain and food. Adoption and learning variables also revealed information on farming system long-term viability and productivity, as well as integration into the monetary economy. A brief description of each study approach is provided below.

Description of the study sites

During the learning phase, studies were carried out in Malawi's major groundnut producing districts of Nkhotakota, Mchinji, Kasungu and Mzimba. For comparisons, farmers from Dowa, a non-project intervention site, were used as the control population (Fig. 1). Studies were undertaken in the districts of Chikhwawa, Nsanje, Karonga, Mchinji, Mzimba, Lilongwe and Dedza during the scaling-out phase, with farmers from Balaka serving as the control population for comparisons (Fig. 1). These districts are illustrative of Malawi's three agroecologies: low altitude (200–700 m above sea level), with ≤ 600 mm of annual rainfall; mid-altitude (650–1300 m above sea level), with ≤ 800 mm of annual rainfall; and high altitude (> 1300 m above sea level), with ≤ 1000 mm of yearly rainfall [38]. The districts of Nkhotakota, Chikhwawa, Nsanje, Karonga and Balaka occur in the low-land agroecology, while Mchinji, Kasungu and Dowa occur in the mid-altitude agroecology, and Mzimba, Chitipa, Rumphi are occur in the highland agroecology. All these agroecologies experience tropical dry and semi-humid weather, which favours Aspergillus fungal infection of developing groundnut pods, subsequently producing aflatoxins as they mature [38, 39]. Previous research in Malawi found an inverse association between annual precipitation and aflatoxin contamination of groundnut grain, with lowland crop, contamination being higher than mid- and high-altitude crop contamination [38]. Farming communities were mobilized through collaborations between civil society and farmers.

Study 1: Technology access through community seed banks

The learning phase

CSB formation

The initial task in this phase, was to establish CSBs in the study districts. Project partners held consultative meetings with agricultural communities in each district to: (a) choose a crop enterprise that was profitable and crucial for their livelihoods and, (b) to identify the major problems restricting its production to marketing. In every district, groundnut was the most preferred crop. Under the guidance of local leaders and extension staff, an average of 16 farm-families were constituted into each CSB. Members of each CSB were mostly from the same community, and or Malawian public extension management system. A CBS management committee was formed, to oversee CSB operations, consisting of a chair, secretary, treasurer and three committee members, one of whom was in charge of seed production quality assurance. Training, production quality assurance, seed storage, and engagement with other actors such as researchers, extension staff and or traders were all regular CSB operations. Men and women were encouraged to serve on management committees at each CSB. The CSBs were either hosted by farmer organizations like the National Smallholder Farmers' Association of Malawi (NASFAM) and Ekwendeni Mission Hospital's Malawi Farmer-to-Farmer Agroecology initiative (MaFFA), or formed from independent farmer clubs created by the public agriculture extension service. Basic storage infrastructure and extension support was provided by hosting organizations, while farmer clubs identified a trusted member with enough and suitable storage facilities to store their seed. Typically, such a farmer was a trusted and well-known community leader. ICRISAT trained the lead-farmers on good agronomic practices for grain and seed production,

[1] Lead-farmers are usually people, who may be retired local community leaders and or active civil servants of both gender, most of whom are literate, who disseminate knowledge in their communities by training fellow farmers and hosting result-demonstrations.

[2] Aflatoxins are mycotoxins with known human and livestock health risks, produced by some types of fungi following their colonisation of grain [37].

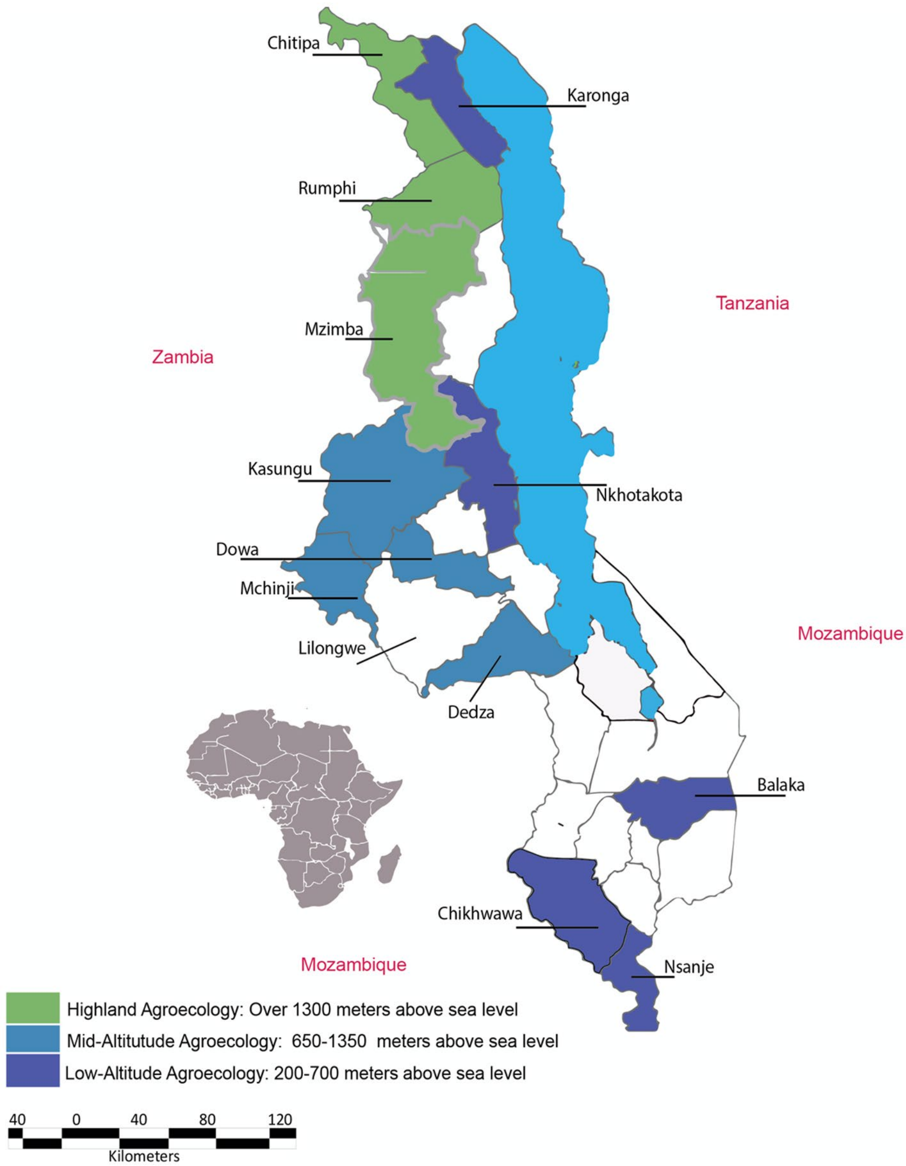

Fig. 1 Map of Malawi showing study the sites in different agroecologies of the country. The designations of the districts indicate where the farmers who took part in the study live. Agroecologies have been shaded differently. The large bright-blue body on the right-hand side of the figure is lake Malawi

leadership and group dynamics, informal seed system management, and aflatoxin mitigation. Public and partner extension personnel stationed at the research sites, received similar training to the lead-farmers, and were in addition given training materials to support lead-farmer training sessions. To demonstrate their dedication to the group, every CSB member paid 500 Malawi Kwacha (equal to US $3 at 2011 exchange rates), to contribute to the cost of storage facility maintenance. In total, 45 CSBs were established in four study districts from 2010–2011 to 2014–2015 cropping seasons.

CSB operations

Each CSB got start-up seed from ICRISAT and each beneficiary farmer received 10 kg of basic (foundation) seed[3] of improved groundnut, which was utilized to produce the initial volume of quality-declared seed based on accepted management regulations set by the CBS (Fig. 2).

[3] A class of seed used to produce certified seed. Certified seed is the grade sown by farmers for grain production. In this study, a high-grade seed class was used to guarantee production of at least four generations of high-quality seed, when production prerequisites are met.

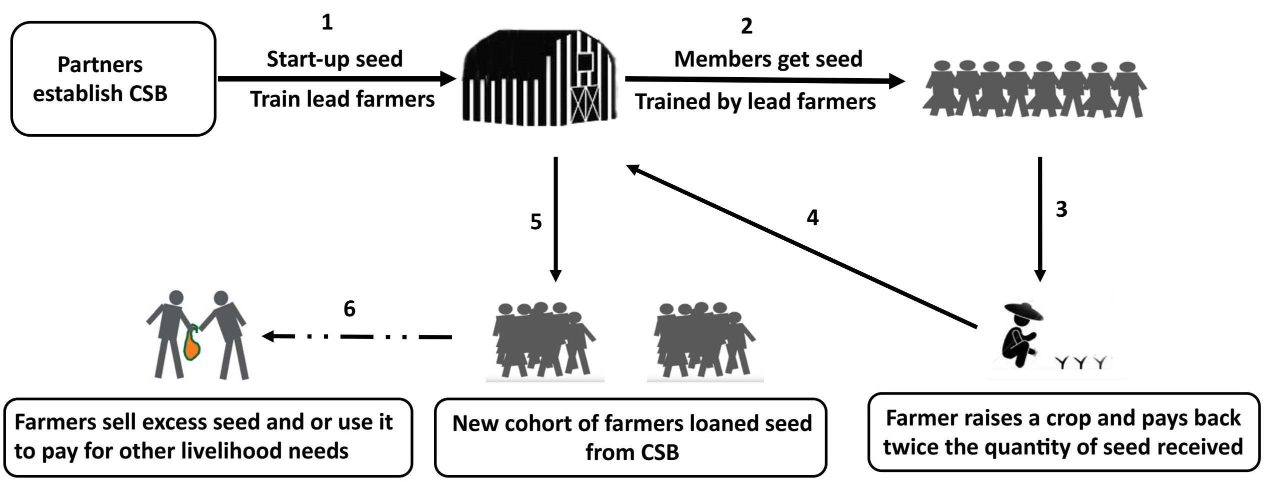

Fig. 2 Processes of a community seed bank are depicted in this conceptual diagram. Seed banks are established by partnering with beneficiary communities and training lead-farmers and extension staff, who then train additional farmers to produce seed on loan from the seed bank. Farmers may collaboratively train and control their seed crop this way

Standard seed production guidelines were used to raise the seed -crop that was supervised to maturity by a lead-farmer who also served on the management committee. The lead-farmers were supported by ICRISAT and field extension professionals. The CSB management took note of any production issues which would inform future decisions on a members performance, especially if he/she failed to pay the seed -loan. The crop was harvested at maturity, and the principal benefactor repaid the borrowed seed, with interest (i.e., twice as much or 20 kg). Members who knowingly failed to repay seed, were de-registered and barred from participating in any future CSB activities (training, access to markets, etc.). If a member's loan payback failure was due to circumstances beyond his/her control, he or she was given a second seed -loan and the production -to -repayment process was repeated. Partial loan repayment was rolled over to the next cropping season. All repaid seed was stored centrally at the CSB, and distributed to a new group of beneficiaries the next cropping season. As a result, the number of beneficiaries doubled with each new cropping season, as new farmers got seed and then repeated the cycle. Beneficiaries were encouraged to sell excess seed to other farmers within their communities, extending the reach of technology even further, while still maintaining enough seed for themselves to expand crop acreage. After 4 years of implementation, adoption of improved groundnut varieties by CSB members was investigated in Mchinji, Nkhotakota and Mzimba districts. Mzimba is a vast district that is administratively separated into two management units: North and Mzimba management units. Three CSBs were randomly selected in each district, and 25–28 were randomly selected farmers to participate in the study (Table 1). Each participant filled out a basic questionnaire about the amount of seed they got, the sources of seed they utilized for planting the following crop, and how they used harvested seed after repaying the seed -loan. This information was then compared to the research baseline data.

The scaling-out phase study

The CSB approach used in the learning phase and its modified version, were utilized to scale-out seed of

Table 1 The study population from communities engaged between 2010 and 2015, the research learning phase

District	Number of community seed banks/farmer groups	Number of respondents	
		Beneficiary households	Non-beneficiary households
Kasungu[a]	5	55	
Mchinji	3	58	
Mzimba[b]	6	73	
Nkhotakota	3	40	
Dowa[c]	–	0	77
Total	17	226	77

[a] Farmers from Kasungu supplied grain samples for Aflatoxin B1 contamination assay. They had been trained separately, and earlier than the main study population

[b] Mzimba is Malawi's largest district. It is sub-divided into two administrative units of Mzimba North and Mzimba South. Three CSBs, per administrative unit, were engaged for the study

[c] Farmers from Dowa are not beneficiaries of the project and provided research control samples for Aflatoxin B1 assay

underinvested crops in the 2016–2017, 2017–2018 and 2018–2019 cropping seasons. Seed storage, recruitment of a new tier of beneficiaries, and subsequent training, were all done on an individual basis using the modified CSB approach. This approach is ideal for small-seeded crops since it avoids the requirement for big storage facilities, which we found to be a prevalent restriction in some rural areas. New crops such as pigeon pea, common bean, sorghum, pearl millet and rice were introduced during this phase in addition to groundnut. The CSB approach described in the learning phase was used to promote groundnut and common bean; whereas, the modified approach was used to promote sorghum, pearl millet and pigeon pea. The second group of beneficiary farmers, once trained and technically supported by the nucleus farmer, produced high-quality seed and likewise, recruited two new beneficiaries, thereby expanding the beneficiary population. After three-to-four generations of implementation, seed may be refreshed to maintain high productivity. Beneficiary farmers at that point in time would also graduate to efficient seed and grain producers ready to participate in the monetary economy.

To investigate results of CSBs during the scaling-out phase, productivity changes among beneficiaries in seven districts, was assessed. In the 2016–2017 cropping season, 21 CSBs were chosen and followed up in the 2017–2018 and 2018–2019 cropping seasons. In each CSB, an average of 15 members were randomly selected from membership lists kept by CSB leaders, generating at least 300 respondents per cropping season. The control population for comparison was 200 non-beneficiary farmers per cropping season, from the same districts, as the CSBs. These control farmers were identified by local extension officers in the research focus districts. Farmers who had not interacted with the research were asked to fill out a brief questionnaire by extension officers and the information generated was subsequently used by the project team to identify the control population. Control farmers on the whole had not received training or seed and were not affiliated with CSBs. The explanatory variable of the number of training received, was used to identify non-beneficiaries. Over the three cropping seasons, 917 beneficiary households and 653 non-beneficiary households were interviewed (Table 2).

Data management and analytical framework

Learning phase

Districts within the same agroecology were treated as replicates, with all farmers receiving the same training and crop varieties. In each district, three CSBs were randomly selected for data collection. Assembled data were subjected to analysis of variance using GenStat 19th Edition and means compared, using Fisher's protected least significance difference test at $P \leq 0.05$.

Table 2 The study population from communities engaged between 2016 and 2019, the research scaling-out phase

District	Number of community seed banks	Number of respondents	
		Beneficiary households	Non-beneficiary households
Nsanje	2	113	81
Chikwawa	2	123	87
Dedza	4	201	89
Mzimba	4	135	156
Mchinji	4	135	91
Karonga	3	111	78
Balaka	2	99	71
Lilongwe	3	144	84
Total	24	1016	737

Scaling-out phase

Crop production and productivity data collected from CSB members during the scaling-out phase were analysed with descriptive statistics and a generalized linear model using Stata 14.2.1 statistical package. The generalized linear model was preferred to ordinary least square regression model, because the distribution of residuals was not normally distributed. Secondly, because yield is a function of a number of independent and linked explanatory variables, the generalized linear model was the most appropriate framework for statistical analysis. Linked explanatory variables, for instance, district of groundnut production, is linked to agroecology, market access and access to extension and advisory services. We did not apply inorganic fertilizers, a commonly used variable in yield regression modelling, because it is not a common practice for groundnut production in Malawi. The independent variables were: district of crop production, number of training sessions received during the study period, gender and age of farmer, level of education and crop variety grown. There variables were converted into dummy variables during the analysis. The model used was:

$$g\{E(Y)\} = \beta 0 + f_1(x_1) + f_2(x_2) + \cdots + f_n(x_n), \quad (1)$$

where $\beta 0$ = Constant; $X_1 \ldots X_n$ = independent variables, Y = grain yield in kg/ha

$$\begin{aligned} gE(Y) = \beta 0 &+ f(\text{age}) + f(\text{education}) + f(\text{district}) \\ &+ f(\text{sex of farmer}) \\ &+ f(\text{number of training on groundnut productivity received}) \\ &+ f(\text{groundnut variety grown}). \end{aligned} \quad (2)$$

Study 2: Knowledge access through farmer-to-farmer approach

Good agronomic practices

The efficiency of the farmer-to-farmer knowledge dissemination approach was investigated for 3 and 4 years, in Kasungu and Mchinji, respectively, by leveraging social networks of CSBs. The research was carried out in three stages. In the first stage, the research team trained public and or civil society extension staff, on good agronomic practices for groundnut grain and seed production, as well as aflatoxin mitigation (food safety). Theoretical knowledge was presented over the course of three days, with three follow-up sessions, spaced out over important stages of crop development. Hands-on training sessions was done at learning sites in fields that hosted result demonstrations, as described for the theory training sessions. In the second stage, lead-farmers were identified from the beneficiary population, and subsequently trained by the extension staff. Lead-farmers received the same training as the extension staff, with the exception that they were required to attend multiple follow-up sessions throughout the cropping season as determined by their extension staff trainers. In the third stage, lead-farmers trained other farmers in their communities on crop production and food safety at various stages of crop growth. Farmer-field-schools were used to train all three learner-types, as this approach allows for interactive, problem solving and discovery based hands-on learning. Beneficiary farmers, met once a week in groups of 25–30 people at a farmer-field-school site, where they were trained by a lead-farmer on production-through-post-harvest management of the priority crops, using a curriculum developed by the research team. This process was used in 50 and 30 farmer-field-schools in Kasungu and in Mchinji, respectively.

Food safety

Training of different learner-types on aflatoxin contamination and its effects on food safety and trade, as well as the mitigation technologies, was done as described for good agronomic practices. In May 2014, the end of the cropping season, 715 groundnut grain samples were collected from 143 groundnut fields belonging to lead-farmers and their student farmers, in Mchinji and Kasungu (mid-altitude agroecology) and Mzimba (high-altitude agroecology). Samples were collected in May, to facilitate assay for aflatoxin contamination of grain immediately after harvest. Previously, we found that low aflatoxin contamination is expected in freshly harvested grain if mitigation measures are applied [40]. Additionally, with the help of local leaders, samples were collected from groundnut producers in Dowa, a mid-altitude agroecology district. Dowa was a non-research intervention site that provided groundnut grain samples for comparisons. In Mchini and Kasungu, lead-farmer and beneficiary lists were utilized to choose participants at random for sample collection, whereas in Dowa, randomly identified farmers provided grain samples. In each field, at least five grain samples were collected, dried to 7–10% moisture content, and 20 g of the dried grain tested for Aflatoxin B1 (AFB1) contamination using enzyme linked immune sorbent assay (ELISA) [40].

Table 3 Changes in sources of improved variety seed sown by farmers during the learning phase

Seed source	Baseline 2010–2011 cropping season (%)	2014–2015 cropping season (%)
Community seed bank	2.4	84.3
Fellow farmers[a]	0.9	11.5
Local markets[b]	20.6	3.2
Own seed[c]	76.1	1.0
Total	100	100

[a] These farmers obtained seed from fellow farmers in their communities as a gift or as payment for services offered

[b] These farmers planted seed bought from local grain dealers in their communities and or open markets

[c] These farmers planted own-saved seed to produce the next crop. Usually such seed is recycled for many generations

Data management and analytical framework

Data from the two studies conducted during this period were all subjected to analysis of variance as described for the learning phase. To assess learning by the target population, adoption of aflatoxin mitigation methods based on the level of aflatoxin contamination in their groundnut grain, post-training was used. As appropriate, the generalized linear analysis was performed.

Results

Access to new technologies through community seed banks and the benefits

Seed and allied agri-innovations were delivered using CSBs. The proportion of farmers accessing seed from CSBs increased by 35-fold, from 2.4% in the baseline cropping season (2010–2011), to 84.3% at the end-line (2014–2015) cropping season. The number of CSBs increased by 7 fold from 45, in 2010 to 314 in 2015, serving over 15,000 individual farmers directly, with women accounting for 47% of the total population. During the same period, the proportion of farmers utilizing own-saved seed, declined from 76% in 2010, to 1% in 2015 (Table 3). In cropping seasons when rainfall was adequate, seed -loan repayment was up to 80%, but never

Table 4 Changes in access to quality seed by rural farmers of Malawi during the learning phase

District	Sources of seed at baseline—2010–2011 (%)				Sources of seed at end-line—2014–2015 (%)			
	Seed bank[a]	Fellow farmers[a]	Local markets[a]	Own seed	Seed bank[b]	Fellow members[b]	Local markets[a]	Own seed
Mchinji	0.00	1.20	35.00	63.80	92.00	2.00	5.00	1.00
Nkhotakota	0.00	0.50	1.00	98.50	82.50	9.25	6.50	1.75
Mzimba North	10.00	1.00	15.00	74.00	73.70	24.40	1.20	0.70
Mzimba South	0.00	0.92	30.00	69.08	90.00	10.00	0.00	0.00
LSD ($p \le 5\%$)	2.49	0.79	13.31	36.79	12.70	4.74	1.17	1.02

[a] Improved seed but non-certified, usually of grain quality

[b] Certified seed of the quality-declared class

Table 5 Different uses of harvested groundnut grain by CSB beneficiary farmer in four districts of Malawi during the learning phase.

District	Proportionate (%) utilization of excess groundnut grain produced by beneficiaries		
	Sold to grain off-takers	Used as gift	Payment for labour
Mchinji	90.0	5.3	75.0
Nkhotakota	94.8	2.0	32.7
Mzimba North	90.7	15.6	55.0
Mzimba South	95.0	10.0	64.7
Mean	92.63	8.23	56.85
F-value	0.63	88.10***	138.90***

*** Highly significant, $p \le 0.001$

$n = 104$

below 50%, even in years when the weather was unfavourable. Seed -loan repayment was relatively higher among men at 80%, compared to women at 67%.

Analysis of variance revealed significant differences between seed sources at the baseline and end-line, respectively (Table 4). At the end-line (2014–2015 cropping season), whereas most farmers used improved seed from CSBs, farmers in Mzimba-North and Nkhotakota districts proportionately had fewer farmers doing so, compared to farmers in Mchinji and Mzimba-South (Table 4).

Analysis of variance showed new technologies have a beneficial impact on community livelihoods, with 92.6% of farm-households selling surplus grain to earn revenue to meet their basic needs (Table 5). Only 16% of groundnut grain harvested was given as a gift, indicating a greater focus on monetized transactions or payment for services such as labour. Overall, 77% of households said they were more food secure because they could buy maize, the staple grain, during lean periods, before the next harvest, and diversify their diets using groundnut crop sales revenue.

Farmers who adopted improved groundnut varieties, had a 1.83 fold increase in grain yield, compared to those who grew Chalimbana, a local land race, used as the control check during the scaling-out phase (Table 6). This increased yield, allowed households to expand the crop area under improved varieties to 1.8 ha, from an average of 0.11 ha, further securing their livelihoods (data not shown). Although there were differences even within the same botanical group, short duration (Spanish groundnut varieties) Kakoma and Chitala, were better adapted, than mid-duration (Virginia varieties) Chalimbana, CG7 and Nsinjiro. Nsinjiro the best performing Virginia variety, had lower productivity of 64.7 kg/ha and 83.7 kg/ha, than the Spanish varieties, Kakoma and Chitala, respectively.

Table 6 Mean groundnut productivity (kg/ha), among beneficiary farmers during the scaling-out phase

Variety	Botanical group	Crop duration (days)	Respondents	Yield (kg/ha)	Yield difference over local check (fold)
Chalimbana (local check)	Virginia	150	104	697.2	
Kakoma	Spanish	90	135	1258.0	1.81
Chitala	Spanish	110	133	1276.7	1.83
Nsinjiro	Virginia	120	133	1193.3	1.72
CG 7	Virginia	120	135	1124.4	1.61

F-value = 4.807 $p \le 0.001$

Table 7 Changes in productivity of six crops during the scaling-out phase in seven districts of Malawi

Crop species	2016/2017		2017/2018		2018/2019	
	Yield (kg/ha)		Yield (kg/ha)		Yield (kg/ha)	
	Beneficiary	Non-beneficiary	Beneficiary	Non-beneficiary	Beneficiary	Non-beneficiary
Groundnut	1065**	809**	808	744	848*	668*
Common bean	1019***	784***	750*	601*	672*	504*
Pigeon pea	737***	346***	765**	504**	872**	526**
Sorghum	1196	1008	856*	677*	1275**	989**
Pearl millet	1014***	521***	564*	322*	658**	389**
Rice[a]	1405	1388	2311	2105	1971	1881

$n = 917$ for the beneficiary farmer population and $n = 653$ for non-beneficiary farmer population

*** $p \le 0.001$, **$p \le 0.05$, *$p \le 0.1$

[a] Rice farmers obtained seed from researchers and not from CSBs. Non-beneficiary rice farmers either planted own-saved seed or obtained it from civil society and or commercial retail agro-dealerships

The productivity disparities between CG7 and the two Spanish varieties were considerably greater with Kakoma and Chitala producing 133.7 kg/ha and 152.3 kg/ha, respectively.

All new varieties matured earlier by over 30 days, compared to the local land race Chalimbana, giving farmers more time to engage in other profitable activities (Table 6). With exception of rice, grain yield was significantly higher ($p \le 0.05$) among CSB beneficiaries than among non-beneficiary farmers (Table 7). Grain yields varied seasonally for most crops across the 3-year study period, but with 2016–2017 cropping season, having the highest grain yields. Using the 2016–2017 cropping season as an example, the difference in productivity between beneficiary and non-beneficiary farmers was 19, 30 and 32% for sorghum, common bean and groundnut, respectively, and was highest in pearl millet (95%) and pigeon pea (113%). The difference in grain yield of rice between beneficiary and non-beneficiary farmers was 1% and it was not statistically significant.

Knowledge access through farmer-led systems

Good agronomic practices

Analysis of variance on adoption of new varieties and the utilization of aflatoxin mitigation measures by CSB beneficiary farmers in the three study districts, during the learning phase, was statistically significant ($p \le 0.05$) (Table 8). Many farmers deployed yield-enhancing technologies such as groundnut rosette disease-resistant varieties, compared to aflatoxin contamination mitigation measures. Relatively more farmers in Mchinji and Nkhotakota adopted aflatoxin mitigation measures, compared to farmers in Mzimba. Up to 78.7% of respondents used at least one of the three improved varieties: 80.2% of farmers planted their crop early, in the right plant population, and kept them weed-free to control groundnut rosette disease and support vigorous crop growth, while 68.2% of the respondents used in situ water harvesting techniques for harvesting and retaining water between plant rows, a technique, that minimizes end-of-season drought, a contributing factor to aflatoxin contamination in groundnut (Table 8).

When compared to the commonly cultivated land race, Chalimbana, the adoption of improved varieties, Kakoma and Chitala, and their production agronomy, enhanced grain yield by 502 and 504 kg/ha, respectively. Other popular improved varieties had a substantial yield advantage, such as Nsinjiro (414 kg/ha) and CG7 (366 kg/ha) (Table 9). During the study period, Dedza district experienced unfavourable groundnut production conditions, with farmers experiencing yield losses of up to 212 kg, compared to farmers from Balaka, a drought-prone

Table 8 Adoption of groundnut productivity and food safety-enhancing technologies in three districts of Malawi. $n = 161$

District	Frequency of technologies/knowledge utilization		
	Improved varieties	Aflatoxin mitigation[a]	Groundnut rosette disease mitigation[b]
Mchinji	80.00	72.00	92.00
Mzimba	68.00	68.00	72.00
Nkhotakota	88.20	64.70	76.50
Means	78.73	68.23	80.17
LSD ($p \le 5\%$)	30.72	3.73	3.34

[a] This includes use of in situ water harvesting, a technique that involves blocking of adjacent ridges to prevent water run-off, increasing water seepage in the ground. Increased soil moisture minimizes end-of-season drought, a contributing factor to fungal infection of developing groundnut pods and subsequent aflatoxin contamination of grain

[b] Groundnut rosette disease is the most devastating disease of the crop that can cause up to 100% yield loss

Table 9 Key factors influencing adoption of productivity-enhancing agri-innovations in Malawi during the scaling-out phase

Variable	Coefficient	*Z* value	*P* >|*Z*|
Age	56.42	0.49	0.688
Education	91.73	0.86	0.496
Districts (agroecology)[a]			
Dedza	−220.82	−1.96	0.050*
Lilongwe	632.11	2.79	0.005**
Mchinji	72.56	−0.70	−0.487
Sex of farmer	11.60	0.36	0.716
Training sessions received			
Two	89.12	0.80	0.425
Three	306.21	2.79	0.005**
Four	780.00	7.57	0.000**
Five	1120.51	11.06	0.000**
Variety grown[b]			
Kakoma	502.00	6.23	0.000**
Chitala	504.05	6.27	0.000**
Nsinjiro	414.34	5.14	0.000**
CG 7	366.54	4.56	0.000**

n = 917 for the beneficiary population and n = 653 for non-beneficiary population

* Significant at $p \leq 0.05$

**Significant at $p \leq 0.001$

[a] Districts represent three agroecologies of Malawi where studies were conducted. Crop productivity among non-beneficiary farmers in Balaka was 646.03 kg/ha, *n* = 91

[b] The local check Chalimbana against which improved groundnut varieties were compared produced 697.2 kg/ha

district. The study also found no influence of gender, on access to training, as women and men benefited equally.

Food safety

Aflatoxin contamination in grain samples from beneficiary and control non-beneficiary farmers was significantly different ($P < 0.05$), indicating that learning occurred, through changes in mitigation management behaviour (Table 10). Compared to grain samples from non-beneficiary farmers in Dowa, the comparator district, grain samples got from Mchinji and Kasungu beneficiary farmers, had a higher frequency of staying within the Government of Malawi's permissible aflatoxin level in food products of 20 parts per billion (ppb), indicating that learning had occurred. Despite the fact that Mzimba farmers had received aflatoxin mitigation training, their grain was more contaminated than of trained farmers from Kasungu and Mchinji (Table 10). These findings also support the use of farmer training, with a threshold of three training sessions, serving as the minimal number required to initiate and maintain learning (Table 10). Overall, farmer training, when combined with the use of improved varieties, grown in an appropriate agroecology, increases productivity, allowing farmers to meet their livelihood needs easily.

Table 10 Changes in aflatoxin contamination of groundnut samples from trained farmers in Mzimba, Mchinji and Kasungu districts during the learning phase

District	AFB_1 range	Frequency of Aflatoxin B1 (AFB1) concentration (ppb) in grain samples	
		Grain containing less than 20 ppb[a]	Grain containing more than 20 ppb[b]
Mzimba	0.4–633.9	31.00	69.00
Mchinji	0.0–42.9	74.00	26.00
Kasungu	0.6–138.9	72.00	28.00
††Dowa	0.0–191.4	50.00	50.00
Means		56.80	43.30
LSD ($P < 0.05$)		9.96	26.39

[a] ppb = parts per billion. 20 ppb is the Government of Malawi and generally accepted international upper limit for aflatoxin contamination of grain and or food products [39, 40]

[b] Farmers from Dowa district did not benefit from research interventions and supplied control grain samples

n = 143

Discussion

The purpose of this study was to see how effective farmer-led technology and knowledge delivery systems are at enhancing agri-innovation delivery to rural smallholder farmers of Malawi. Two integrated studies were carried out in two phases: a learning phase (from 2010–2011 to 2014–2015 cropping seasons), and a scaling-out phase (from 2016–2017 to 2018–2019 cropping seasons). According to the studies, CSBs, an informal farmer led system for production-to-delivery of seed have shown a consistent improvement in access to improved seed of underinvested crops. During the learning phase, access to improved seed grew 35-fold, from 2.4% to 84.3%, while farm-saved seed usage fell from 76 to 1%. This demonstrates learning by the farming communities, a change in behaviour through adoption of improved crop agronomy and or technology use. It also suggests that rural households, many of whom are marginalized, are getting more access to improved seed and good production knowledge. In Bangladesh, a farmer led project increased access to improved wheat seed, enabling poor and ultra-poor farmers to earn more than half of the income required to break through the poverty line in their locations [41]. Similar reports on improved access by rural communities to improved varieties has been reported in India, [33]. Interestingly, seed -loan repayment was generally higher among men (up to 80%), compared to (67%)

among women farmers. The reason for this is because men took complete management control of their seed -crop, including loan payment, especially when the man was a CSB member. Women on the other hand, only had partial control over their seed -crop in some situations, especially, when their family hired farmland for production. Women also utilized some of their seed harvest for food, which had an impact on loan repayments, particularly if the harvest was poor. Furthermore, these findings demonstrate that farmer led approaches can improve to access science solutions for rural farming households, that have been left out by private sector technology delivery services. Farmers who used new groundnut varieties and improved agronomy, saw grain yields improve by up to 1.8-fold (Table 6). This grain yield, in the case of groundnut, is higher than that reported during the same period, namely 754 ($\pm$186) kg/ha [42], and shows that smallholder farmers are adopting improved agri-innovations (improved varieties and good agronomy). Overall, these findings support the effectiveness of CSBs in providing improved seed and other livelihood benefits, particularly to marginalized rural farmers.

During the scaling-out phase, informal seed systems applied to several crops significantly increased grain yield (Table 7). While there were seasonal differences across production years, the trend was increasing. The difference in productivity between CSB beneficiary and non-beneficiary farmers, in 2016–2017, the best cropping calendar year, ranged from 15% in sorghum, to 30 and 32% in common bean and groundnut, respectively, with pigeon pea, at 113% being the highest. This demonstrates that informal seed systems can be tailored to a variety of crops, for which farmers can produce quality-declared seed. Quality declared seed is considered a lower class of seed than certified seed. However, the difference is usually small for self-pollinated crops, especially during the first three generations of a crop cultivated from basic/foundation and or certified seed, as was the case in this study. Given the limited access to seed of improved varieties in many developing economies [43], 44], we suggest that CSBs offer an alternative route for effective last mile delivery of improved seed. For crops well supported by private sector and government investments, such as maize in Malawi, sowing of modern varieties, while improved [12], in general, crowds out other food security crops [13, 45]. As a result, in many developing countries, the use of CSBs is critical for unlocking agricultural productivity. In fact, up to 90.2% of farmers in many rural communities of developing countries, obtain seed from informal sources [9], and this study, finds that across crop species, such systems are adaptable and scalable.

The excess grain generated by CSBs is also a strong boost to the economy, both rural and urban, with farmers selling up to 90% of surplus grain to generate revenue for their household needs, including food and farm labour (Table 5). The contribution to improved livelihoods is evidently strong in this study, with up to 77% of households being more food secure. In another study, per capita groundnut consumption in these study districts, increased from 4 to 9 kg across the study period [21], enhancing access to protein and other nutrients that are limited in diets of many Malawian farm-households [46, 47]. A vibrant groundnut-food processing industry, including therapeutic foods, has been fostered by the supply of low aflatoxin contaminated grain. Malawi now produces a ready-to-eat therapeutic food, developed by Valid Nutrition, a civil society initiative, for rehabilitating severely malnourished children, which is sold locally and or exported. Groundnut a key ingredient in the therapeutic food product that provides energy, protein and a variety of essential nutrients [48].

Despite this, the relative impacts of these interventions particularly at the community level, are less in locations where markets for grain and agri-input supply systems are weak such as in Mzimba (Table 4). This indicates the need for strong market systems, as is the case for rice. Rice grain is in high demand in Malawi, with off-takers offering competitive prices that catalyse farmer investment in productivity-enhancing innovations. This explains the non-significant differences in rice grain yield, between CSB members and non-beneficiary farmers (Table 7). Groundnut, a crop with a high elastic demand, responds to market forces in a similar way. Grain markets in large metropolis such as Lilongwe, Malawi's capital, pay well for good quality attracting investments in aflatoxin management. Because of the lack of conformity to trade sanitary and phytosanitary conditions, groundnut grain prices in Mzimba were comparatively lower, ranging from 11 and 20% between 2015 and 2018, with no differential pricing for grain (Tables 8, 7). This study further finds that rural farmers, like modern market driven farmers, place premium on technology that improve their livelihood opportunities. Farmers adopted more production-input related innovations such as improved varieties and good crop agronomy, than aflatoxin mitigation measures, indicating that grain yield is the single most important metric of return-on-investment, and for that reason farmers, are ready to invest in it. As a result, new crop varieties must have larger grain yield than older ones.

The high level of adoption of new agri-innovations, delivered though farmer led systems, provides strong support for their effectiveness. We find that a threshold of three training sessions, is sufficient for rural farming households to learn (Table 9). Participatory and inclusive training approaches such as farmer-field-schools and result-demonstrations, increased proximity of learners to trainers, a system suitable for adult education [49]. Accordingly, farmer led knowledge dissemination systems should be structured to give at least three in-person training sessions, preferably, supported by result-demonstrations of new technologies in target communities. Taken together, this article has demonstrated the effectiveness of a twinned-approach for technology and knowledge delivery, employing farmer led systems, that empower farmers and produces positive outcomes when integrated in local community and farmer organization operations. For economies with limited investments in agricultural extension and weak agri-input delivery systems, this study recommends these alternative low-cost, integrated but impactful approaches for supporting agricultural transformation and development.

Conclusions

Private sector-led systems are limited in scope and scale of their business emphasis for under-resourced, difficult-to-reach rural farming communities, preventing them from accessing advanced genetics and agronomy to solve their farming needs. Furthermore, this study recognizes the challenge rural smallholder farmers face in accessing advisory services. The research shows how an integrated farmer-led knowledge and technology delivery system may remarkably improve productivity from field to post-harvest, allowing rural farm-households to grow their agricultural operations. It proposes a threshold on the number of training sessions required to initiate and sustain learning, as well as a tried-and-true informal seed system, the CSB, for increasing production, access and demand for improved seed, therefore opening up opportunities for private sector investment, as seed demand grows. These farmer-led technology and knowledge disseminations systems are scalable in a variety of farming contexts as precursors for leveraging science solutions for crops production, where private sector is underinvested and public extension and advisory services are underfunded.

Abbreviations

CARE: CARE International; CIMMYT: International Maize and Wheat Improvement Center; CSB: Community seed banks; EPA: Extension planning areas; FAO: Food and Agriculture Organization of the United Nations; FtF-MISST: Feed the Future Malawi Improved Seed Systems and Technologies; ICRISAT: International Crop Research Institute for the Semi-Arid Tropics; MaFFA: Malawi Farmer-to-Farmer Agroecology Project; MSIDP: Malawi Seed Industry Development Project; NASFAM: National Smallholder Farmers' Association of Malawi; TFP: Total Factor Productivity; USAID: United States Agency for International Development.

Acknowledgements

The authors acknowledge the support provided by all public extension officers in the Extension Planning Areas (EPAs) of: Kasungu EPAs—Chipala and Lisasadzi; Lilongwe EPAs—Chileka, Mitundu, Ukwe, Chitsime, Chigonthi and Malingunde; MchinjiEPAs—Mkanda, Mlonyeni, Zulu and Msitu; Mzimba EPA's—Bwengu, Zombwe, Emfeni, Luwelezi, Mbawa and Mjinge and Nkhotakota EPA—Linga; Dowa EPA—Dzoole; Dedza EPAs—Linthipe Golomoti, Lobi and Mtakataka; Chikhwawa EPA- Dolo, Mitole and Kalamba; Nsanje EPA—Nyachilenda and Makhanga; Chitipa EPAs—Misuku and Kameme; Rumphi EPAs—Bolere and Mhuju; Balaka EPAs—Phalula, Bazale and Rivirivi; Karonga EPAs Vinthutukutu and Lupembe We are also grateful for the leadership and technical services provided by field extension staff of NASFAM from the following Associations—Nkhotakota—Linga North and Linga South; Mzimba—Elangeni, Luwasozi and Luwasozi and Mchinji —Kalulu and Mikundi. We thank the leadership of Ekwendeni Mission Hospital, "Malawi Farmer-to-Farmer Agroecology (MaFFA) project, especially Ms Lizzie Shumba, who supported research activities in Mzimba. Finally, we thank the following ICRISAT field officers: Christopher Kachusa, Napthali Mbale, Chisomo Ngombe and Sidney Kanyenda who supported the research. Analysis of aflatoxin was done by Nelson Kumwenda and Joseph Maruo both formerly of ICRISAT. The following research assistants supported data collection and the team is grateful for their work, i.e. Madalitso Chiphiko, Gift Twanje, Linda Chavula, Roselyn Kasunda and Emmanuel Mtambalika. The support by farmers who participated in the research is acknowledged. Graphics were prepared by Lawrence Lazarus formerly of ICRISAT.

Author contributions

PO is plant breeder and seed systems specialist who led the MSIDP Phases I and II teams, as well as the FtF-MISST project. He led the design and execution of the studies as well as data analysis and drafting of the manuscript. He is based at ICRISAT in LM. WM is a research associate with ICRISAT. He implemented activities during the learning phase, as well as data management and manuscript drafting; EC, formerly of ICRISAT, was responsible for training activities during the learning and scaling-out phases. She is employed by FAO Malawi. TC, of ICRISAT, was responsible for training activities during scaling-out phase. HM formerly of ICRISAT, conducted the socio-economic surveys, data analyses and drafted the manuscript; HC is research associate with ICRISAT, who implemented activities during the learning phase and supported data management; SC formerly of ICRISAT, was a Project Manager for FtF-MISST, who oversaw activity implementation and data collection during the scaling-out phase. FS formerly of ICRISAT, was a Project Manager for MSIDP who oversaw activity design, implementation and data collection during the scaling-out phase in northern and southern regions of Malawi; AS is a Nutrition Scientist with ICRISAT. She led the design and implementation of aflatoxin mitigation activities, as well as manuscript preparation; BC is an Economist leading NASFAM. She led project implementation and manuscript development. EM is a plant breeder formerly with ICRISAT. He was involved in the design and implementation of some learning phase activities as well as review of this manuscript. MS is an agronomist and seed systems specialist, formerly with ICRISAT, who oversaw the design and implementation some activities during learning phase under MSIDP Phase I, and subsequently reviewed the manuscript. He is now based at CIMMYT, Nairobi. RC is a plant breeder and coordinator of Southern African Bean Research Network at Alliance Bioversity-CIAT, Malawi who led the bean research activities of MSIDP. All authors read and approved the final manuscript.

Funding

Financial support for this work was provided by the MSIDP Phase I and II funded by Irish Aid, FtF-MISST funded by USAID (Grant Number AID-BFS-G-II-00002-14 Amendments No. 8 & 9 Number MTO 069018), New varieties and management systems to improve productivity, food security and safety and market competitiveness Funded by McKnight Foundation (Grant No 14-320); MSIDP also covered the cost of publication for this article.

Availability of data and materials

The data supporting the results of this article are included within the article; detailed data are available from the corresponding author, and on reasonable request, will be made available from ICRISAT repository.

Declarations

Ethics approval and consent to participate

Ethical approval for the study regarding aflatoxins was obtained from the National Health and Science Research Committee of Malawi (Approval

Number NHSRC 773). Additionally, consent to participate in the studies by farmers was sought prior to engagement by all participants in surveys, on-farm trialling and training. In the case of extension workers, approval was sought from their employer, through their nomination and or engagement in the research activities.

Consent for publication
We approve the publication of this manuscript.

Competing interests
All authors declare they have no competing interests.

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Received: 6 September 2021 Accepted: 19 May 2022
Published online: 08 July 2022

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