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RESEARCH

How do multi-stakeholder partnerships influence access to quality bean seed and variety turnover? Lessons from Burundi and Zimbabwe

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Background

Crop breeding is an important pathway for increasing yield potential and one of the strategies used to adapt smallholder agriculture to climate change in developing countries (Marcho et al. 2020). Genetic gains, however, go to waste if farmers do not access modern varieties at the right time (before seed deteriorates) and pace. This problem is prevalent in developing countries and is manifested in slow varietal turnover and low agricultural productivity gains. For example, while 218 maize varieties with a yield potential of 3 to 15.5 tons/ha were released in Kenya in the last decade (KEPHIS 2021), the average age of maize varieties in farmers' fields is 15–20 years (Marcho et al. 2020). Meanwhile the age of rice varieties grown by farmers in India is 25 years (Marcho et al. 2020), yet 78 rice varieties with a yield potential of 3.4 to 7 tons/ha were released between 2009 and 2021 (NRRI 2021). In Ethiopia, 25 improved common bean (*Phaseolus vulgaris*) varieties (Pan African Bean Research Alliance 2022) with a yield potential of 2 to 4 tons/ha (Demelash 2018) were released in the last decade, but the varietal turnover averages 19 years (Habte et al. 2021). Quick variety turnover is not only critical for increasing a crop's yield potential, but has become urgent for crops such as common bean that are highly vulnerable to environmental stresses. These stresses are increasing due to climate change (Atlin et al. 2017).

Accelerating varietal turnover for crops requires understanding not only the superiority of the new varieties over old ones but also how innovations in seed systems contribute to overcoming slow uptake of new crop products. The autogamous nature (self-pollinated crop/limited genetic deterioration) of the grain legumes (Rubyogo et al. 2019) allows farmers to recycle seed severely. The consequence is slow variety replacement rates and uncertain demand that has been a consistent challenge for private seed suppliers in creating stable bean seed demand given low profit margins (FAO 2010). Because of this, engaging the formal seed sector has remained elusive since private seed companies have not yet found it lucrative to engage in bean seed production (Rubyogo et al. 2019). The situation has been exacerbated by institutional constraints such as use of strict and very specialized standards that increase the cost of certified seed production. The public sector dominance of the upstream seed supply also constrains the accessibility of early generation seeds by private seed producers due to lack of sufficient capacity[1] within National Agricultural Research Systems (NARS) (Barriga & Fiala 2020; Mastenbroek et al. 2021).

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[1] This conventional model is weak because NARS often do not have sufficient capacity: machinery, human resource (skilled and unskilled), and funds to produce sufficient volumes to stimulate market demand. Also, the model is unidirectional – top down, which limits opportunities for upstream expansion.

In the last two decades, there has been concerted effort to improve legume seed systems and to increase seed production to facilitate uptake of new varieties and replace old varieties, via increased partnerships (Monyo 2016; Rubyogo et al. 2019; Varshney et al. 2019). In particular, the Alliance of Bioversity International and the International Center for Tropical Agriculture (ABC) together with the National Agricultural Research Institutes, under the umbrella of the Pan African Bean Research Alliance (PABRA), have since 2003, introduced multi stakeholder partnerships (MSPs) in bean seed systems of Sub-Saharan Africa (Rubyogo et al. 2010). In 2003 for example, CIAT spearheaded the development of a framework for wider dissemination of improved bean varieties that introduced MSPs as a key aspect of bean research in Sub-Saharan Africa (Assefa et al. 2006; Rubyogo et al. 2010). This framework has transformed bean seed systems from centrally monopolized formal seed delivery to a decentralized multi-stakeholder-based seed system (Rubyogo et al. 2019). Partnership with seed companies and NGOs influenced use of inclusive seed packages affordable by small-scale growers while at the same time, increasing the number of varieties distributed through formal systems. Community based quality declared seed enterprises have also been widely promoted as part of MSPs and a new seed subsystem for supplying new bean variety seed to farmers in geographical areas not served by the formal seed sub-system (Tebeka et al. 2017). Research has shown that community based bean seed enterprises are profitable and have a potential to deliver bean seed in marginal areas (Katungi et al. 2011; Munyaka et al. 2017; Tebeka et al. 2017).

Creating and coordinating partnership with seed companies, NGOs/CBOS, and promoting community-based seed businesses in seed delivery has been accompanied by an increase in the number of actors in seed production who later contribute to increasing the volumes of quality seed of improved bean varieties on the market. Here, seed value chain actors are trained in quality seed production and marketing. Indeed, the last two decades of concerted development of the bean seed system by ABC and NARS has been characterized by growth in the use of improved bean varieties in Sub-Saharan Africa from 15% in 1998 (Johnson et al. 2003) to an average of 30% in the region by 2012 (Muthoni and Andrade 2015). Table 1 shows adoption levels of improved bean varieties in PABRA countries.

In this study we discuss the effects of multi stakeholder partnerships in facilitating access to quality seed of improved bean varieties and examine their subsequent effect on varietal turnover. Various studies have analyzed the role played by MSPs in delivering legume seed to farmers including those in marginal areas (Iorlamen et al. 2021; Ojiewo et al. 2020; Rubyogo et al. 2019). These have highlighted the ability of MSPs to foster delivery of improved legume (including bean) variety seed, increase adoption, and thus increase legume production and productivity. However, these studies use descriptive methods that often do not control for cofounding factors when analyzing the impacts of interventions including MSPs. Thus, there is still a dearth of empirical research that has applied rigorous econometric methods to assess the effect of MSPs on farmer access to quality seed, and their impacts on variety turnover. The results from this study serve to offer accountability for development investments, and inform design and implementation of policies targeting legume seed systems in the developing world.

This study sought to bridge this gap by combining the endogenous treatment effects model/multinomial endogenous treatment (for Burundi) and change in change model (for Zimbabwe) to (1) estimate the impacts of a multi stakeholder partnership driven bean seed system on smallholder farmers' access to quality bean seed. Impact is represented by indicators that measure different dimensions that define a seed system: seed access and seed quality. We use a subjective measure of access (such as farmers' levels of satisfaction with variety, seed package size and price) and an objective measure (use of improved variety) as indicators of access. (2) Evaluate the effect of the MSP on farmers' participation in formal (certified seed) and semi-formal (quality declared seed) seed markets and (3) estimate its effect on varietal turnover in Zimbabwe and Burundi. A key effort today by breeders and seed systems experts is to reduce the average age of varieties in farmer's fields so as to increase productivity and resilience since new varieties embody better genetics.

Zimbabwe and Burundi benefited from the Swiss Agency for Development and Cooperation (SDC) project[2] between 2014 and 2021 as flagship countries in developing bean seed systems because they were emerging out of crisis. Burundi had suffered domestic political upheavals while Zimbabwe had experienced economic breakdown that ensued after land reforms. The crisis in each country had caused significant disruption in production systems, including decline in access to improved varieties. The project deemed that access to seed, for a staple crop like beans, was critical for the return to normalcy of life in the two countries. The project matched MSPs to the seed systems context of each country and

[2] Project interventions targeted smallholder farmers with an overall goal of improving access to quality seed of improved bean varieties through supporting the bean seed system to deliver quality seed and right varieties that are high in productivity.

Table 1 Percent of farmers growing improved bean varieties in select PABRA member countries

Region/Country	Year of study	Percent of farmers growing improved bean varieties	Source
ECABREN			
Burundi	2018	72.0	Katungi et al. 2020
Rwanda	2011	86[a], 50[b]	Larochelle et al. 2016
Tanzania (South)	2013	53.8	Letaa et al. 2015
Ethiopia	2016	57	Habte et al. 2021
Uganda	2012	26.0	Larochelle et al. 2015
DRC (East)	2007	28.0	Dontsop et al. 2016
SABRN			
Zimbabwe	2016	35.6	Katungi et al. 2017a, b
Zambia	2013	26.9	Hamazakaza et al. 2014
Malawi	2013	69.0	Katungi et al. 2017b
Mozambique	2014	25.0	Maereka et al. 2015
WECABREN			
[c]			

[a] Climbing bean variety

[b] Bush bean varieties. East and Central Africa Bean Research Network (ECABREN), West and Central Africa Bean Research Network (WECABREN), South African Bean Research Network (SABRN). Countries presented based on data availability and the most recent study published online.

[c] Information of adoption rates was not available for WECABREN countries.

used them to disseminate improved variety seed. For example, in Zimbabwe the project partnered mainly with seed companies who produced and supplied seed to farming communities. Since Burundi did not have formal seed companies at the time, emphasis was placed on growing the number of community-based seed producers (from a baseline of 10 in 2014 to 55 in 2019 and partnering with NGOS to disseminate seed to farmers. In both countries, interventions such as field demonstrations, farmer field days, agricultural shows, seed fairs, and participatory variety selection were used to raise awareness and further dissemination efforts.

Our results show that the MSP approach was associated with significant improvement in access to quality seed of improved bean varieties in Burundi and Zimbabwe. We also found that the approach resulted in this effect through two main pathways: (1) reduced the distance between farms and bean seed sources by leveraging on its ability to bring together partners and (2) increased volumes of seed produced and disseminated. The MSP also reduced the area weighted average variety age, and farmers were satisfied with varieties delivered through the system. Thus, the MSP in bean seed systems served to diffuse new improved varieties through expanding linkages between the formal and informal systems to quicken access to new variety seed. The MSP could thus be an effective instrument for delivering new varieties to farmers.

Dimensions of assessing an efficient seed system

Four main dimensions have been proposed for assessing the efficiency of a seed system: seed access, quality of seed and varieties supplied, sustainability and suitability of seed systems, and promotion and awareness creation by a seed system. For brevity and lack of data to assess it, we leave out the sustainability and suitability of seed systems dimension and review the other three dimensions.

Seed access

According to FAO, (2016), seed access can be defined as the ability and willingness to acquire seed through a desired source/option. Important components of seed access include seed *availability*, the *amount of seed planted verses actual requirements*, and seed *affordability*. *Seed availability* as a component of seed access considers the quantity of seed produced, its distribution, and spatial spread. Just like any supply chain system, the quantity of seed produced is an indication of the ability of the seed system to respond to demand (Christopher 2011). At times, researchers assume that the seed produced is what seed producers supply in the market and is used by farmers. This reveals that measurement of seed availability sometimes falls short of capturing the disparity between seed production and supply by producers and use by farmers. For the *seed acquired and planted*, two aspects are important (Maereka 2020): (1) the amount of seed acquired that is actually planted, and (2) the proportion of new variety acquisitions to the farmers' total variety portfolio. The first aspect helps to eliminate carry over seed in assessing actual seed acquisitions, while the second assesses new seed acquisition from different seed sources. The final dimension for access is the *affordability* of seed. Quality seed may be available in the community but not affordable by all either due to supply side constraints when priced highly or demand side barriers such as when farmers lack the purchasing power. In this paper, we approximate affordability using the farmers subjective rating of the fairness of prices paid for bean seed, difference between the prevailing seed price and grain price, the difference between the price of improved and local varieties and the difference between the price of seed bought from a formal source and seed bought from an informal source including that bought from community seed producers (price variation by seed type).

Quality of seed and varieties supplied

As a dimension of seed system efficiency entails meeting the desires of genetic purity of seed, seed health, and the physiological quality of seed as required by farmers. These can be assessed by observing the 'truthiness to type' of the seed supplied (varietal purity), uniformity in germination, high germination and vigor, freedom from designated diseases, and optimum moisture. Verification during seed production through field inspection, and seed testing are often used to assess these parameters at the seed supplier level. However, this kind of data is always not available for assessing the quality dimension of seed accessed by farmers at the time of purchase. Truthiness to type has also received growing attention as a measure of seed quality with some studies using DNA fingerprinting to assess the truthiness to type of varieties grown by farmers (Maredia et al. 2016). However, because DNA fingerprinting of seed system is costly, its parameter has so far been adopted in studies measuring adoption and impacts of improved varieties (Habte et al. 2021; Maredia et al. 2016). To a farmer, variety quality is not limited to truthiness but also its genetic superiority, i.e., about how well it performs in the garden, on the plate and market. For example, low variety turnover has been associated with limited gains in productivity (Maereka 2020). Thus, variety quality can be assessed by taking farmer's subjective ratings of the level of satisfaction with the bundle of traits for seed they use. In this paper we use farmer subjective ratings of variety attributes (i.e., production, market, and consumption traits) as key dimensions of the quality of varieties supplied.

Promotion and awareness creation by a seed system

Given spatial and temporal difference in seed and variety requirements, performance of a seed system is also pegged on information availability and avenues for creating awareness. Knowing the diversity and functionality of information sources is thus critical. Various approaches including multistakeholder partnerships/platforms (Rubyogo et al. 2010, 2019), capacity building and skilling of key seed system actors (Monyo 2016), and development of product specific profiles and catalogues have been used as critical approaches for targeted dissemination of variety and seed information. Having diverse information sources could improve access and thus performance of a seed system.

The structure of seed systems and synopsis of bean seed system interventions in Burundi and Zimbabwe

Structure, conduct and performance of the bean seed system in study sites

In Burundi, the bean seed system is dominated by the informal sector that serves the needs of most smallholders: 936,155 bean farmers.[3] The informal seed sector accounts for a significant portion of bean seed that farmers use every season in Burundi (Bararyenya et al. 2012; Mabaya et al. 2021). Seed in the informal sector is supplied through use of own saved seed and farmer to farmer seed exchange (barter, cash or gifts). While the public sector still controls much of the upstream part of the seed system, farmer based, and community market led enterprises play a pivotal role in creating exposure and popularizing these public varieties. They conduct demonstrations, outreach, media promotions and other seed promotion related events to advertise new improved varieties. Several of the varieties managed by bean seed systems in Burundi are from the Institut des Sciences Agronomiques du Burundi (ISABU) a public research institution and are released and promoted as public varieties. A lack of licenses and seed companies to disseminate these varieties has hastened the role of the informal seed sector. Burundi also boasts of the semi-formal seed sector where community-based organizations and trained individual farmers do the production and marketing of seed of improved and landrace varieties (Mabaya et al. 2021).

The formal bean seed system in Burundi is centralized with a vertical unidirectional flow of different seed classes (Fig. 1). Burundi's supply of bean seed through the formal sector is to a considerable extent still under government control. The agricultural research institution (ISABU) has a national mandate of developing improved bean varieties, maintaining germplasm and producing

[3] FAOSTAT 2022, estimated that total harvested dry bean area in 2018 was 599,139 Ha, while each farmer cultivated an average of 0.64 ha (Katungi et al. 2020).

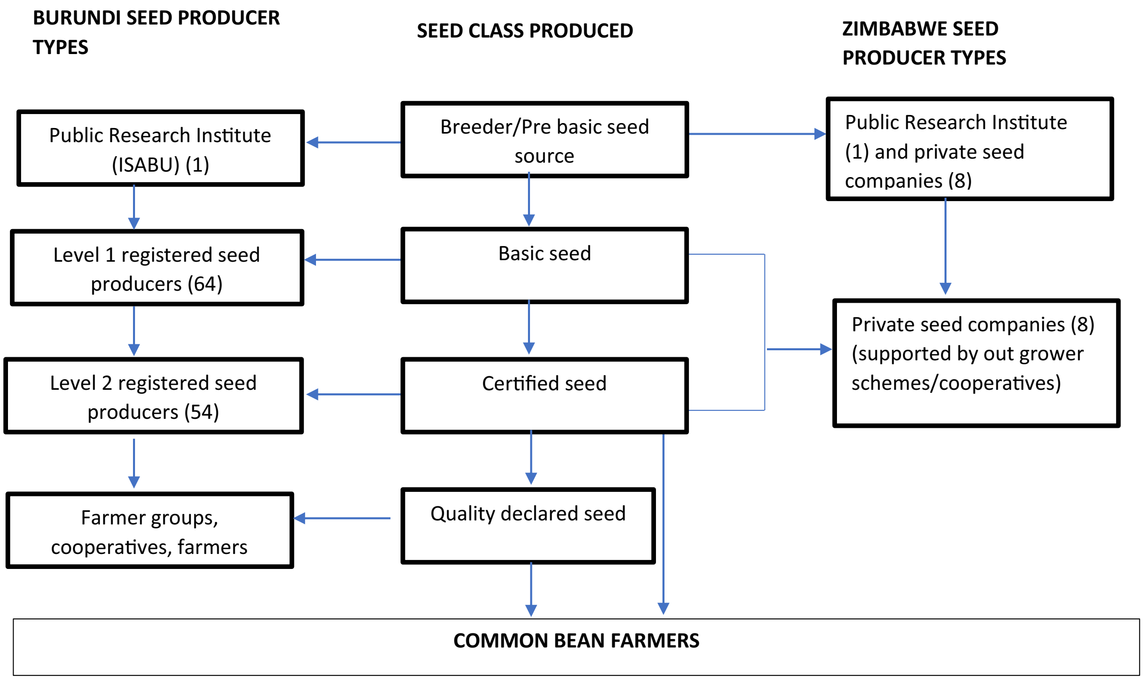

Fig. 1 The nature of bean seed systems in Burundi and Zimbabwe. Source: Author conceptualization of literature reviewed

both foundation and pre-basic bean seeds. Thus, 100% of pre-basic bean seeds are produced by ISABU, which then sells pre-basic bean seeds to level-1 bean seed producers registered by the National Office of Control and Seed Certification (ONCCS) to produce basic bean seeds. By 2020, Burundi had 64 seed producers in this category including individual producers and seed cooperatives; and one seed company (Mabaya et al. 2021). Basic bean seed is then sold to 54 level-2 seed producers that are also registered by ONCCS to produce certified bean seeds. Beyond this level, two pathways exist for the production of grain for consumption: (1) The certified bean seed goes directly to farmers or (2) the certified seed is supplied to non-registered farmer cooperatives or farmer associations for the production of Quality Declared Seed (QDS), who then supply farmers to produce grains for consumption. In 2020, Burundi had 16 known non-registered farmer cooperatives or farmer associations that supplied QDS.

The top four (four-firm concentration ratio) bean seed producers in Burundi have a market share of 96% and a Herfindahl–Hirschman Index of 8885 suggesting very low levels of competition in Burundi's bean seed market (Mabaya et al. 2021). In terms of variety portfolio, by 2020, ISABU together with partners had released 45 varieties (Nduwarugira, et al. 2020). This is approximately 13,314 hectares per variety released. However, eleven of the released varieties[4] dominate the bean production system and account for 75% of bean production. Thus, there is 24% use of varieties released.

In Zimbabwe, the formal and informal seed systems coexist to facilitate access to bean seed (Fig. 1). For example, up to 50% of the seed used by bean farmers in 2016 came from seed purchases and 40% of the seed was retained or carry over seed (Katungi et al. 2017a, b). Privately bred bean varieties (about 54% of seed sold) dominate the bean seed supplied in Zimbabwe (Maereka 2020), making promotional activities by seed companies biased towards their own varieties. The country has a highly specialized and restricted seed system with highly regulated and strict standards in production and postharvest handling of the seed, which necessitates seed company licensing. In 2016, Zimbabwe had 16 active seed companies of which eight produced and or marketed bean seed (Mabaya et al. 2017). According to FAOSTAT, 2022, a total of 26,702 hectares of dry beans were harvested in Zimbabwe in 2018 and with an average area planted per household of 0.41 hectares (Katungi

[4] RWV1272 (12.1%), G13607 (TWUNGURUMURYANGO) (11.1%), MUKUNGUGU (9.9%), MUHORO (7.4%), MAC 44 (6.91%), IZO201543 (MAKUTSA) (6.2%), VCB81013 (5.9%), DORE DE KIRUNDO (5.7%), NOKIA (3.5%), CODMLB003 (MUTWENZI)(3.21%), and NUV30 (MAKAKI) (3.2%).

et al. 2017a, b)—about 65,484 bean farming households in Zimbabwe service the current bean seed system.

Public bean research and seed services (certification and inspection) are undertaken by the Department of Research and Specialist Services (DR and SS). However, private seed inspectors also support the seed sector. While the private sector has its own bred bean varieties, some varieties bred by DR and SS, for example high iron beans, are promoted in partnership with private seed companies. This collaboration coincided with the government's policy of promoting nutrition through fortification programs. The policy influenced seed companies to embrace partnerships with public breeding programs for them to access bio fortified beans—thereby strengthening the linkage between the private and public sector to contribute to the distribution of seed from public breeding programs. Once Zimbabwean farmers gain access to certified bean seed from seed companies, horizontal farmer to farmer seed supply mechanisms often facilitate further seed dispersal.

Unlike Burundi, with a diverse bean variety portfolio, of the 26 released bean varieties (Pan African Bean Research Alliance 2022), five bean varieties[5] accounted for 86% of the cropped area in Zimbabwe. This could be explained by the differences in variety maintainers/origin, number of released varieties, and total area under beans. In terms of breeding performance, Zimbabwe has high variety release intensity (0.0002 varieties per Ha) compared to Burundi (0.00008 varieties per Ha) as well as high utilization of varieties released. The intensity of formal bean seed system in Zimbabwe is quite high, with 3337.8 hectare per Seed Company compared to Burundi (599,139 per Seed Company). Two (PAN 148 and Sc Bounty) of the five varieties that account for 28.5% of adoption in Zimbabwe are from private seed companies. Just like other legume seed, the supply of bean seed through the private sector is limited which caused the need for the formation of registered farmer associations and cooperatives to supplement bean seed supply. Farmer seed grower's associations and cooperatives can be registered with the seed certifying authorities to produce, and market bean seed through seed companies (Munyaka et al. 2017).

Seed system interventions to accelerate adoption and reduce variety turnover under SDC

The interventions under the SDC project aimed to enhance the performance of the seed systems in the two countries by targeting increased accessibility by farmers to seed of high quality and of new improved bean varieties. This was to be achieved through strengthening linkages between the formal and semi-formal seed systems, creating and strengthening partnerships, as well as seed production and dissemination and variety popularization. A Multi-Stakeholder Partnership approach was used to fast track the implementation of these interventions for wider impact. The funding from the project was meant to catalyze investment and action from different bean seed value chain actors that become part of the MSP.

In Burundi, 13 high yielding bush and climbing bean varieties with an average age of 2.6 years were identified and disseminated to smallholder bean farmers through a seed system that integrated operations of multi-stakeholder partners with field demonstrations and participatory variety selection. Quality seed of improved varieties was bundled with crop management practices (i.e., in agronomy and post-harvest handling). The project was implemented in 78 (72%) of the 108 communes in Burundi. The primary communes that received intensive MSP interventions were 41% while 31% received low intensity interventions. Those that never received any intervention (28%) are classified as the control group in this study.

The critical aspect in popularizing and boosting new bean seed demand that was adopted by the SDC project in Burundi was to allow organic growth in seed supply by using the power of multiple actors that are involved in the bean sector. Critical here was the identification and prioritization of the right market class of improved bean varieties (like those widely demanded by farmers and the market). The NGOS/CBOS with an interest in bean and the project mobilized and formed partnerships to leverage on their resources and networks in scaling up dissemination of these varieties. For example, some NGOS constructed community stores for seed producers and bought seed from seed producers for redistribution to farmers.

In Zimbabwe bean seed interventions were implemented as a collaboration of research and several bean sector actors including NGOs, private seed/input suppliers, agro-dealers, and farmer organizations in 17 districts that were selected across all bean producing provinces. The districts were: Matobo, Mwenezi, Gwere, Masvingo, Chikomba, Kadoma Municipality, Zvimba, Seke, Marondera, Makini, Nyanga, Mutasa, Murewa, Uzumba Marimba, Chamanimani, Chipinge and Harare. This was intended to accelerate uptake of improved bean seed and varieties at scale. Project interventions promoted four varieties (i.e., NUA45, Gloria, Cherry, and sweet violet) with an average variety age of 5.5 years and a yield potential of 2.8 tons/Hectare. The initiative

[5] Gloria (27.4%), NUA 45 (22.1%), PAN 148 (19.0%), SC Bounty (9.47), and Cardinal (8.42%).

was a response to declining bean productivity in Zimbabwe that had dropped by 67% between 2010 and 2015 (AGRITEX 2015). A total of 12,635 men, women and youth benefited from various capacity building programs including: bean production/agronomy, variety characterization, marketing skills, record keeping, value addition, integration of gender concerns into community, and household planning. To create wider seed access, the project partnered (signed contracts), with five seed companies in Zimbabwe to multiply and market bio fortified bean varieties.

Thus, project partnerships facilitated the production and dissemination of bean seed of targeted improved varieties, through coordinated actions of diverse partners. This was done by broadening actor networks at various levels to expand spatial coverage—thereby providing seed production infrastructure to support seed production and dissemination. Once seed was made available in the community and nearer the farms, the transaction costs of search, physical transport reduces—making it more affordable by farmers that were previously unable to buy it. Also, with increased local availability (formal and informal seed sources effectively linked), forces of demand and supply should take effect to facilitate further seed dispersal. We anticipated that with wider access to varieties that meet farmers preferences, farmers would replace the old with new varieties thus accelerate variety turnover.

Treatment and outcome variables

The treatment

The project interventions supported a multi-partner system to deliver a bundled intervention package: quality seed of improved bean varieties, and training on the use of complimentary production options to bean farmers. This was done in such a way that some communes/wards benefited while others did not. Therefore, our main treatment group is farmers in commune/wards that benefitted from project interventions (coded as 1) and the counterfactual are those farmers in communes/wards that did not (coded as 0). At this point, the treatment happened at the community level though outcomes were observed at household level. In Burundi, the treatment was also allocated in such a way that some communes did not receive interventions at the same time nor with the same intensity. Thus, making a multi-level treatment analysis possible.

Outcome variables

The study derives outcome variables from the impact pathways presented in Fig. 2. Due to data limitations, the study uses selected seed system dimensions for which data is available. The immediate outcomes of seed accessibility at community level uses availability, participation in seed markets, and the affordability dimension. Here, availability was measured as the distance (kilometers) to the seed source where the farmer treks to buy seed. We consider access to have happened if a farmers started growing a targeted variety within the project period and obtained seed through purchases or project operations. The impact pathway here is that the partnerships, with multiple actors, including seed businesses, brought seed nearer to the farmers, thus easing access. Since participation in seed markets is critical for sustainability, seed purchases (whether farmers purchase the seed—certified or quality declared—they use) is an important dimension of access and we include it in the analysis. This was measured as binary variable taking the value of 1 if the farmer purchased/paid for the seed they used and 0 otherwise. Seed affordability in this study was measured as a farmers perception on the price charged for seed. Farmers were asked to rate the prices paid for seed as fair, high, and very high. We consider seed affordable if a farmer rated the price as fair given the resources they are endowed with.

The study measured the quality of seed and varieties supplied using a subjective assessment of levels of satisfaction with variety production, market, and consumption traits. A seed system is meant to deliver quality seed and acceptable varieties to farmers. As a key outcome, we assess farmer subjective ratings of the quality of the seed that they received/bought from multi-stakeholder partners. Based on a list of variety traits, farmers were asked to rate the importance of each trait in their choice of variety to plant as well as the performance of the major varieties grown at the time of the survey. A five-point scale was used to carry out the rating, with one representing low importance and five high importance. The overall rating of a producer's satisfaction with a variety (or a "satisfaction value") was calculated by multiplying the performance and the importance value.

At the seed system level, we estimate the impact of interventions on community level variety turnover using the Area Weighted Age of the Variety (AWAVA). We postulated that having all the above attributes met by a seed system would encourage farmers to replace old for new varieties, thus higher varietal turnover. To estimate variety turnover, we first obtained a list of all improved bean varieties grown by farmers, their age (based on year of release), and total area under beans in the village. We then estimated the total area[6] under each improved variety in the village and calculate the area share (%) of the

[6] The quantity of seed planted was used a good proxy for area cropped. In small scale mixed cropping systems in Sub–Saharan Africa, it is easier for farmers to recall amounts of seed planted than actual area planted (Larochelle et al. 2015; Katungi et al. 2018).

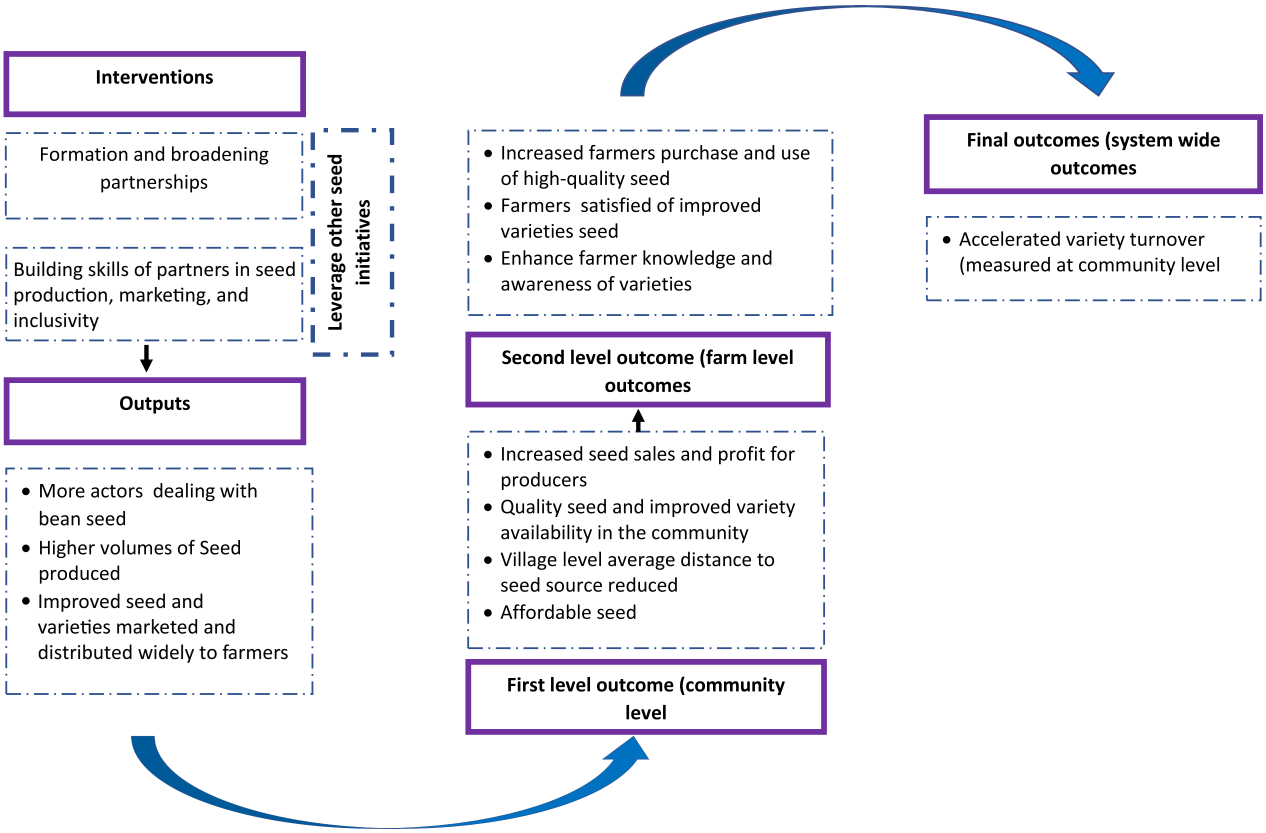

Fig. 2 SDC project seed system impact pathway. Notes: We focused on analysis of select outcomes to inform the impact of the MSP led seed system. This was due to data limitations which constrained us from using all dimensions but selected one to answer questions of whether and how innovations in seed systems influence seed system outcomes

variety. Finally, we weighted the variety age with area share to obtain the AWAVA for each village.

Identification and estimation strategy

To identify the average treatment effect on the treated (ATET), the study used the endogenous treatments effects (ETE) estimator under the control function framework. This was done to control for the possibility of endogeneity and to account for the possibility of self-selection among farmers. Let i denote individual level observations, y_{i1} the potential outcome of receiving the treatment, y_{i0} the potential outcome of not receiving the treatment, t_i a binary treatment indicator and y_i one of our observed outcomes. Furthermore, let X_i denote a set of regressors for outcome models with ϵ_{ij} as an unobserved random component for $j \in \{0,1\}$, and Z_i regressors in the treatment model which may or may not be similar to X_i with v_i its unobserved component. The different treatment effects can be computed as: $y_{i0} = E\left(y_{i0}|X_i\right) + \epsilon_{i0}$ and $y_{i1} = E\left(y_{i1}|X_i\right) + \epsilon_{i1}$. That of the binary treatment is given as

$$t_i = E(t_i|Z_i) + v_i \tag{1}$$

The observed outcome is then given by

$$y_i = t_i y_{i1} + (1 - t_i) y_{i0} \tag{2}$$

Also,

$$E\left(\epsilon_{ij}|X_i, Z_i\right) = E\left(\epsilon_{ij}|X_i\right) = E\left(\epsilon_{ij}|Z_i\right) = 0 \text{ for } j \in \{0,1\} \tag{3}$$

To cater for endogeneity, the conditionality that

$$E\left(\epsilon_{ij}|t_i\right) \neq 0 \text{ for } j \in \{0,1\} \text{ is added} \tag{4}$$

The assumption (Eq. 2) is that the unobserved components in the potential outcome are independent of Z_i implying that the correlation between t_i and the unobserved components must be equivalent to the correlation between ϵ_{ij} and v_i, thus $E\left(\epsilon_{ij}|t_i\right) = v_i \beta_{2j}$. Equations 1, 2, 3 are the basis of the control-function estimator (StataCorp 2021).

To obtain the parameter of interest, Eq. 1 is fitted using a probit estimator. Then $\widehat{v}_i$ is obtained as the difference between the treatment and the estimate of $E(t_i|Z_i)$. The result is used to compute an estimate of $E\left(y_{ij}|X_i, v_i, t_i\right)$ for $j \in \{0, 1\}$. For the linear outcome model,

$$\left(y_{ij}|X_i, v_i, t_i = j\right) = \boldsymbol{X}_i^{'}\beta_{1j} + v_i\beta_{1j} \text{ for } j \in \{0, 1\} \tag{5}$$

and for the probit outcome model, the estimate can be obtained as

$$\left(y_{ij}|X_i, v_i, t_i = j\right) = \Phi(X_i'\beta_1 j + v_i\beta_1 j) \tag{6}$$

The parameters of Eq. 1, 5, 6 and the ATET are estimated using the Generalized Method of Moments (GMM). Here, our parameter of interest, ATET, for the linear (Eq. 7) and probit (Eq. 8) outcomes can be estimated as

$$\frac{1}{n}\sum_{i=1}^{n}\left\{\left(\boldsymbol{X}_i^{'}\widehat{\beta}_{11} + \widehat{v}_i\widehat{\beta}_{21}\right)\frac{n}{n_t} - \widehat{POMO}\frac{n}{n_t} - \widehat{ATET}\right\} = 0 \tag{7}$$

$$\begin{cases} \frac{1}{n}\sum_{i=1}^{n} t_i\boldsymbol{X}_i^{'}\left\{y_i\frac{\phi\left(\boldsymbol{X}_i^{'}\widehat{\beta}_{1j}+\widehat{v}_i\widehat{\beta}_{2j}\right)}{\Phi\left(\boldsymbol{X}_i^{'}\widehat{\beta}_{1j}+\widehat{v}_i\widehat{\beta}_{2j}\right)} - (1-y_i)\frac{\phi\left(\boldsymbol{X}_i^{'}\widehat{\beta}_{1j}+\widehat{v}_i\widehat{\beta}_{2j}\right)}{1-\Phi\left(\boldsymbol{X}_i^{'}\widehat{\beta}_{1j}+\widehat{v}_i\widehat{\beta}_{2j}\right)}\right\} = 0 \\ \frac{1}{n}\sum_{i=1}^{n}(1-t_i)\boldsymbol{X}_i^{'}\left\{y_i\frac{\phi\left(\boldsymbol{X}_i^{'}\widehat{\beta}_{1j}+\widehat{v}_i\widehat{\beta}_{2j}\right)}{\Phi\left(\boldsymbol{X}_i^{'}\widehat{\beta}_{1j}+\widehat{v}_i\widehat{\beta}_{2j}\right)} - (1-y_i)\frac{\phi\left(\boldsymbol{X}_i^{'}\widehat{\beta}_{1j}+\widehat{v}_i\widehat{\beta}_{2j}\right)}{1-\Phi\left(\boldsymbol{X}_i^{'}\widehat{\beta}_{1j}+\widehat{v}_i\widehat{\beta}_{2j}\right)}\right\} = 0 \end{cases} \tag{8}$$

where, $\widehat{POMO}$ and $\widehat{ATET}$ are parameters of the model, and n_t is the number of treated units.

Because we had pre and post treatment data for Zimbabwe we also estimated the Change in Change (CiC) model, proposed by Athey and Imbens, (2006), as a robustness check. The CIC model relaxes several assumptions of the standard linear difference-in-differences model and can estimate models with both continuous and discrete outcomes. It estimates the average and quantile treatment effects of a treatment in settings where repeated cross sections of individuals or panels are observed in a treatment group and a control group, before and after the treatment (ibid). The model has the advantage of providing the entire counterfactual distribution of outcomes that would have been experienced by the treatment group in the absence of the treatment and likewise the untreated group in the presence of the treatment. The CiC model nests the Difference in Difference (DiD) model, thus supplying more information. We adapt and state the final model that we estimated as proposed by Athey and Imbens, (2006). For a detailed discussion of the identification and estimation equations see Athey and Imbens, (2006) and Imbens and Wooldridge, (2009)

Suppose farmer i belongs to one of the treatment groups $G_i \in \{0, 1\}$ with group1 being the treatment group and is observed in time period $T_i \in \{0, 1\}$. The farmer's group identity and time period are treated as random variables. Also, let Y_i be the outcome variable, the observed data are the triple (Y_i, G_i, T_i). For the CiC model with continuous or discrete unobservable characteristics, U_i, of individual i, the effect of the treatment for the second period treatment group is given by

$$\tau_{cic} = E[Y_i(1) - Y_i(0)|G_i = 1, T_i = 1] \tag{9}$$

The first term in Eq. 9: $E[Y_i(1)|G_i = 1, T_i = 1] = E[Y_i|G_i = 1, T_i = 1]$, can be estimated directly from data. Under the assumption of monotonicity and conditional independence of T_i and U_i given G_i, the full distribution of $Y(0)$ given $G_i = T_i = 1$ is identified through the equality

$$F_{Y_{11}}\left(y\right) = F_{Y_{10}}(F^{-1}{}_{Y_{00}}(F_{Y_{01}}\left(y\right))) \tag{10}$$

where $F_{Y_{gt}}(y)$ denotes the distribution function of Y_i given $G_i = g$ and $T_i = t$. Then the expected outcome for the second group under the control treatment is $E[Y_i(0)|G_i = 1, T_i = 1] = E[F^{-1}{}_{01}(F_{00}(Y_{i10}))]$. Athey and Imbens (2006) also provide a detailed explanation of how the counterfactual effect of the intervention on the control group is obtained.

Data

The data used in this study came from the Swiss Agency for Development and Cooperation (SDC) project that was implemented between 2014 and 2021 in Burundi and Zimbabwe. The project aimed to develop pro-poor common bean technologies and create collaborations with a diverse set of actors (researchers, extension personnel, NGOs, private seed/input suppliers, agro-dealers, farmer organizations) to facilitate their uptake at scale. Interventions in seed systems included catalyzing seed multiplication in the formal and semi-formal bean seed sectors and promoting the use of this quality seed of released varieties was at community level.

In Burundi, collection of the data was conducted in July 2019 by ISABU and ABC which elicited information on household demographics, production, and seed use dynamics, and market characteristics. Survey data was

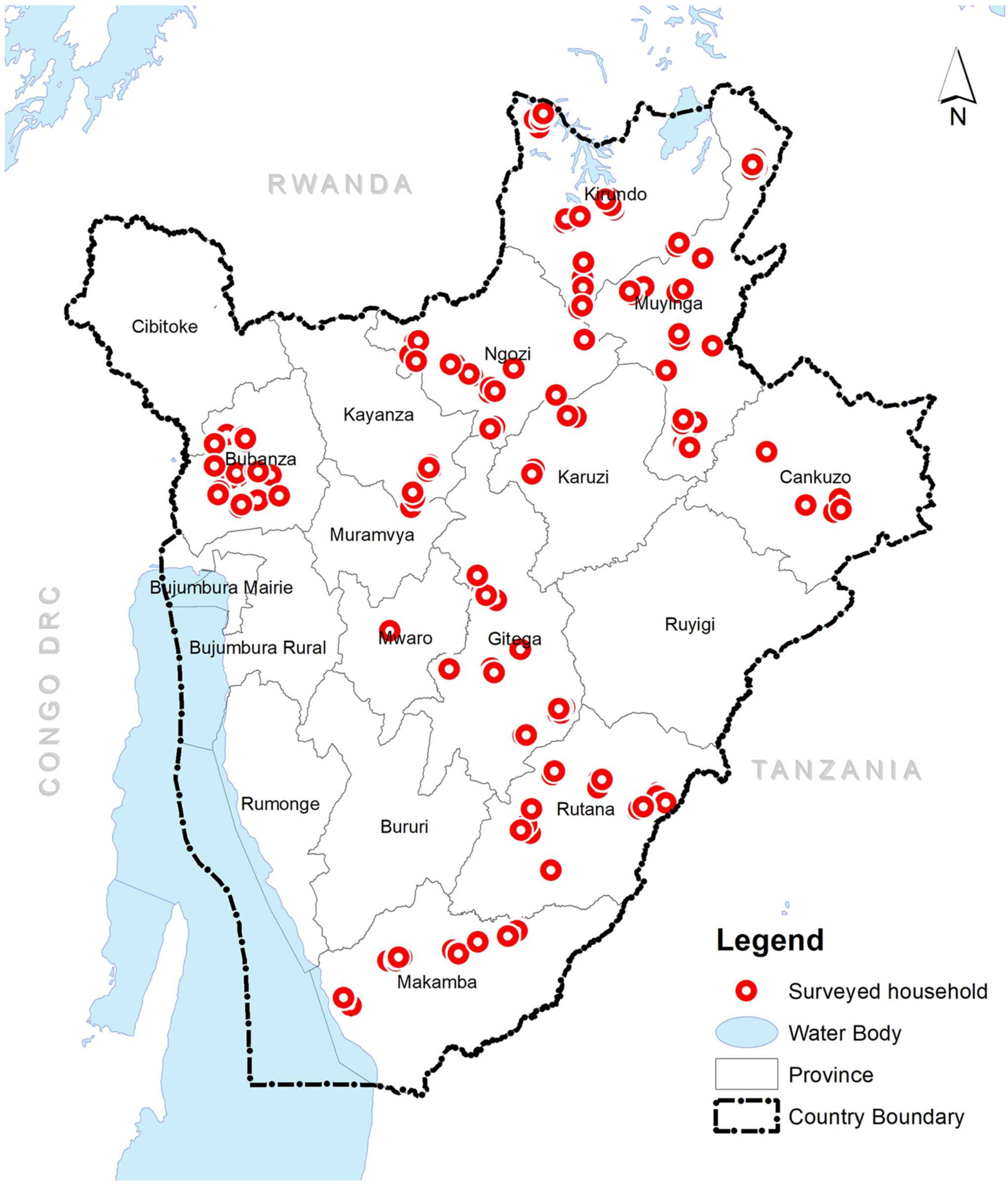

Fig. 3 Map showing surveyed households in Burundi. Source: Katungi et al. (2020)

collected from 805 households in 63 collines (the smallest administrative unit equivalent to villages elsewhere). The sample of households was selected based on a stratified sampling method, with their probability of being chosen proportional to the number of collines in the commune. Sampling was such that selected collines and households were representative of bean growing households in the country.

In Zimbabwe, two rounds of data were collected, one in 2016 (baseline) and another in 2018 (endline) to assess the impacts of seed system interventions instituted. Baseline data was collected from 15 districts, selected using probability proportionate to size sampling whereby the district share of area under bean production in 2015 served as the probability weight. Wards in the selected districts were listed and classified according to project intervention coverage as intervention and non-intervention wards. Households within wards were selected randomly to participate in the study. The same households interviewed at the baseline were also interviewed for the endline survey. Data was collected from a total of 796 household representing 185 wards and of these, 32% of the wards received the intervention. Figures 3 and 4 show

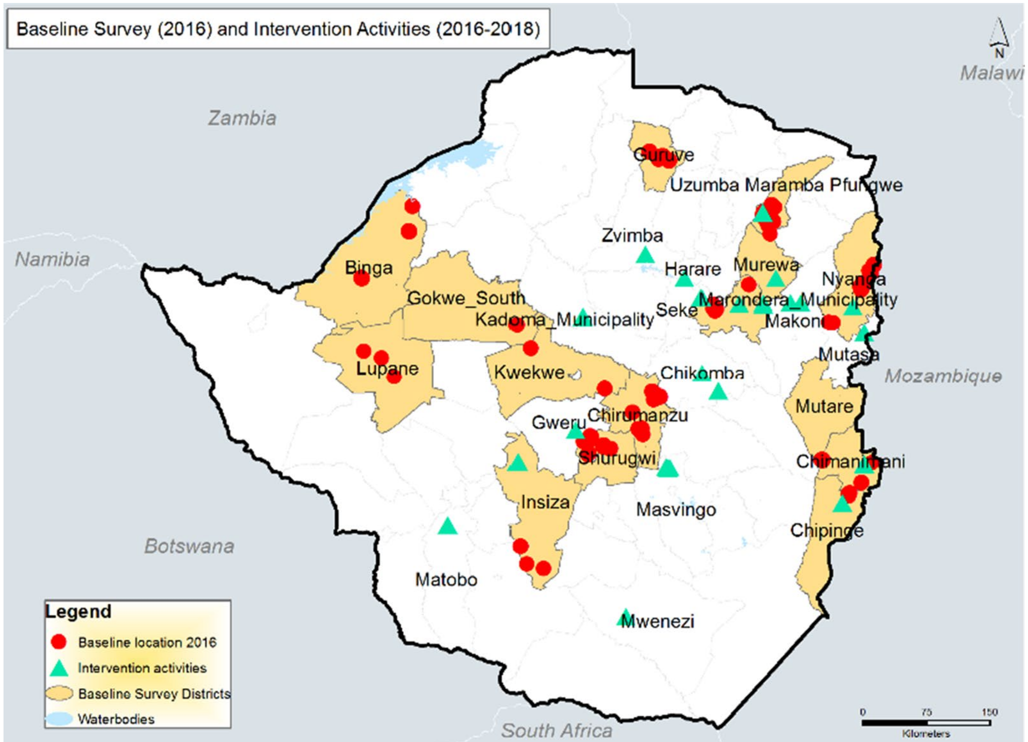

Fig. 4 Map showing surveyed and intervention sites in Zimbabwe

Table 2 Summary of covariate characteristics of farming households used in the study

	Burundi (n = 646)			Zimbabwe (n = 464)		
	Mean (sd) [Control group]	**Mean (sd) [Treated group]**	**p-value of equality between groups**	**Mean (sd) [Control group]**	**Mean (sd) [Treated group]**	**p-value of equality between groups**
Gender of head (1 = Male)	0.87	0.87	0.876	0.78	0.79	0.671
Education of head (Years)	3.25 (3.01)	4.24 (3.41)	0.002	8.14 (2.04)	8.52 (2.13)	0.125
Age of head (Years)	47.10 (13.17)	43.26 (12.15)	0.001	53.89 (12.31)	52.65 (14.39)	0.162
Household size (Number)	6.04 (2.34)	6.51 (2.39)	0.037	5.78 (2.37)	5.95 (2.24)	0.294
Distance to village market (KM)	17.28 (74.68)	15.23 (71.04)	0.802	–	–	–
Grow climbing beans (1 = yes)	0.87	0.78	0.014	–	–	–
Bean area (Ha)	0.42 (0.50)	0.70 (1.72)	0.054	0.95 (1.72)	1.11 (2.06)	0.205
Have cooperative (1 = yes)	0.26	0.48	0.000	0.25	0.27	0.530
Obtained credit (1 = yes)	0.21	0.23	0.671	–	–	–
Have public notice board (1 = yes)	0.08	0.16	0.014	–	–	–
Village has electricity (1 = yes)	0.06	0.15	0.006	0.61	0.51	0.021
Village has market for Ag. Produce (1 = Yes)	0.69	0.76	0.091	–	–	–
Log precipitation	7.05 (0.06)	7.01 (0.10)	0.000	–	–	–
Village receives extension agents (1 = yes)	0.75	0.81	0.141	–	–	–
Average number of irrigated plots	–	–	–	0.39 (0.52)	0.78 (1.04)	0.000
Distance to tarmac road (KM)	–	–	–	15.69 (6.57)	17.24 (7.22)	0.586

locations and surveyed households in Burundi and Zimbabwe respectively.

Table 2 shows a summary of sample characteristics of variables used in the study. Burundian farmers in intervention communities appeared to be better educated, younger, had larger households, had access to public notice boards for information, and resided in villages with electricity. On the other hand, more farmers in the control group grew climbing beans and received more rainfall. In Zimbabwe, the two groups were similar in most aspects except access to electricity and irrigation facilities. With such variations in sampled groups, we cannot rule out household placement bias, which motivated the choice and estimation of the endogenous treatment effects, difference in difference, and the Change in Change models to generate consistent estimates in the empirical analysis.

Results and discussion

Comparative analysis of seed system dimensions by treatment group

We first compare differences between intervention and nonintervention communes/wards for each seed system performance dimension in Table 3. In Burundi, of the 43 communes sampled, 74.4% were under the project intervention area. For Zimbabwe, 30.6% of the 80 wards sampled were under the project intervention area. For the seed access dimension, the aim was to increase access to quality seed of improved bean varieties by catalyzing actor involvement and interest in supplying seed. As a result of project interventions, more farmers in intervention areas in both countries reported having NGO's/CBOs supplying bean seed. Also, in Burundi, intervention areas had more agro input dealers. This reflects achievement of the projects' goal that encouraged multi-stakeholder partnerships. As a result of interventions, fewer farmers (17% less) in intervention areas of Burundi reported problems accessing bean seed compared to nonintervention areas. In Zimbabwe about 78% (31% more) farmers reported using certified seed in intervention communes compared to 47% in non-intervention communes (Table 3). Congruently, fewer farmers used home saved seed. In Burundi, fewer farmers in intervention communes used 'seed' sourced from the grain market, though the grain market remained the major source of seed, supplying 71% of seed, in non-intervention communes and 60% of the seed in intervention communes.

While seed seemed more available, slightly more farmers in Burundi's intervention areas reported planting less seed due to seed unavailability. It is possible that the intervention with modern varieties increased farmer's desire to plant more seed thus the gap. Also, more households reported the presence of NGOs/CBOS supplying free seed, making it available at nonmarket rates (free seed), which may have crowded out private seed business as reflected in lack of effect on participation in seed market by buying seed planted (Table 3). Considering the affordability dimension of seed access, apart from the price of grain, we did not find significant differences between the prices of seed by intervention commune in both countries. Also, there was no significant difference between the mean prices of different seed classes for Burundi while the price for certified seed was significantly higher than other seeds (seed source from community seed producers) in Zimbabwe.

Comparative analysis of outcome variables by treatment group

Table 4 presents a bivariate analysis of the outcome variables of interest to the study. This comparison is based on a simple bivariate analysis and comparison of means. Descriptive statistics show that more farmers in intervention areas, 7% and 24% higher for Burundi and Zimbabwe respectively, had access to seed of improved varieties. Farmers in Burundi that resided in intervention communes sourced bean seed from markets that were about 4 km nearer than farmers in nonintervention communes (Table 4). In Burundi, 57% of sampled farmers reported paying for bean seed in intervention communes compared to 71% in nonintervention communes. The intervention communes in Zimbabwe had a lower area weighted age of varieties, our measure of variety turnover, while there was no difference observed in Burundi.

We also calculated the ratios between prices of different seed classes to assess the intensity of competition among seed dealers in the market. The ratios were as follows for Zimbabwe: Certified: QDS[7] = 0.88, Certified: Grain = 1.59, QDS to Grain 1.80. This shows that certified and quality declared seed are likely to compete on the Zimbabwean market as grain does not seem competitive in the seed market. For Burundi, the ratios were as follows: Certified: QDS = 0.95, Certified: Grain = 0.94, QDS to Grain 0.98. In Burundi, there seems to be tight competition between sellers of seed of all classes. In such a situation, those that supply high class seed may be forced to bid down prices which could reduce the supply of higher-class seed type (Certified) for a lower-class type (QDS or grain used as seed). We present a more robust econometric estimation of the effect of treatment group status on each of the outcome variables by country in the next section.

[7] In Zimbabwe, we considered seed bought by farmers directly from community seed growers/cooperatives as QDS.

Table 3 Summary statistics of the access dimensions of an efficient seed system; comparison of means and proportions between intervention and nonintervention communes (post treatment-2018)

Variable	Burundi			Zimbabwe		
	Mean[a] (se) [For the control group]	diff(se) [intervention less nonintervention area means]	N	Mean[a] (se) [For the control group]	diff(se) [intervention less nonintervention area means]	N
Seed access						
Seed availability						
Gap (Kg) between required and available seed	18.71 (7.04)	7.46 (7.34)	646	7.04 (6.27)	14.70 (11.34)	464
Village has an input dealer (1 = Yes)	0.00	0.16***	646	0.55	− 0.18***	464
Farmers have problems accessing seed (1 = Yes)	0.79	− 0.17***	646	0.68	0.06	464
NGO's/CBOS supplying seed (1 = Yes)	0.26	0.11**	646	0.58	0.19***	464
NGO's/CBOS supplying free seed (1 = Yes)	0.00	0.21***	646	0.49	0.17***	464
NGO's/CBOS supplying credit/sold seed (1 = Yes)	0.26	− 0.10***	646	0.09	0.02	464
Used desired quantity of seed (1 = yes)	0.20	0.01	646	0.52	0.22***	464
Distance (KM) to seed source used by farmers	–	–	–	59.14 (4.80)	8.52 (8.67)	464
Distance (KM) to the nearest certified seed source	–	–	–	78.46 (8.31)	0.74 (12.77)	260
Distance (KM) to the nearest QDS seed source	–	–	–	9.18 (9.59)	20.82 (14.79)	019
Seed bought and planted						
Planted less seed due to unavailability (1 = yes)	0.01	0.06***	646	0.12	− 0.12***	464
Quantity (Kg) of seed planted bought	27.51 (3.81)	6.61 (4.43)	385	34.44 (5.87)	3.63 (10.60)	464
Proportion of seed planted bought	0.18 (0.02)	− 0.06 (0.02)***	646	0.27 (0.03)	− 0.03 (0.03)	
Proportion of farmers by seed type used						
Certified seed	0.22 (0.04)	0.07 (0.04)	646	0.47	0.31***	464
Uncertified seed from community seed producers	0.14 (0.03)	0.07 (0.04)*	646	0.03	0.02	464
Own saved seed	–	–	–	0.37	− 0.19***	464
"Seed" from the market	0.71 (0.04)	-0.11 (0.05)**	646	0.06	− 0.01	464
"Seed" from fellow farmers	–	–	–	0.21	− 0.05	464
Affordability dimension						
Certified seed price (USD/KG)	0.71 (0.14)	0.11 (0.17)	36	12.38 (1.99)	− 5.20 (3.18)†	186
QDS/other seed price (USD/KG)	0.81 (0.59)	0.01 (0.63)	30	14.69 (6.81)	− 6.43 (11.46)†	017
Price of grain used as seed (USD/KG)	0.73 (0.10)	0.14 (0.12)	364	7.90 (2.37)	− 3.40 (4.68)	028
Grain price (USD/KG)	0.46 (0.01)	0.06 (0.01)***	646	1.49 (0.03)	0.13 (0.05)**	374
Size of bean seed packs bought (kg)	–	–	–	4.16 (0.99)	0.04 (0.11)	464
Seed pack size suitability rating						
Small	–	–	–	0.05	0.01	360
Suitable	–	–	–	0.91	-0.03	360
Bigger	–	–	–	0.03	0.02	360

*/**/***Signify significance at 10%/5%/1% level

†Means there is a significant difference between the mean prices of the two seed classes at a 5% level of significance. When not indicated, there was no significant difference between the mean of two seed classes.

Table 4 Summary statistics of outcome variables (post treatment-2018)

	Burundi (n = 646)		Zimbabwe (n = 464)	
	Mean (se) [For the control group]	Diff [intervention less nonintervention area means]	Mean (se) [For the control group]	Diff [intervention less on intervention area mean]
Seed access dimensions				
Access to seed (improved varieties)	0.65 (0.04)	0.07** (0.04)	0.25 (0.02)	0.24*** (0.04)
Distance (km) to the bean seed market	8.93 (0.54)	− 3.97*** (0.61)	59.32 (5.03)	7.091 (2.79)
Variety turnover	9.78 (0.49)	− 0.82 (0.55)	15.44 (0.40)	− 4.42*** (1.20)
Seed market participation (paid for seed used)	0.71	− 0.14***	0.83	0.04
Rating of price fairness				
Fair	–	–	0.42	0.06
High	–	–	0.42	− 0.04
Very high	–	–	0.16	− 0.02
Farmer perception of seed/variety quality[b]				
Satisfaction with production traits	9.88 (0.21)	− 0.32 (0.22)	14.58 (0.21)	0.35 (0.38)
Satisfaction with market traits	10.79 (0.22)	0.00 (0.23)	17.28 (0.21)	0.74 (0.41)*
Satisfaction with consumption traits	11.09 (0.19)	− 0.51 (0.23)**	13.60 (0.18)	0.81 (0.32)**

The table compares the difference in means between groups based on treatment status. */**/*** signify Significance at 10%/5%/1% level.

Empirical results

Table 5 reports treatment effects on various outcomes. Endogenous treatment effects estimates are Average Treatment Effects on the Treated (ATET) clustered at the village level for Zimbabwe and colline level for Burundi. We also report results of multi-treatment level analysis for Burundi estimated using the Multinomial endogenous Treatments Effects model (METE) because we had a multilevel treatment. The CiC estimates are average and quantile treatment effects of a treatment and was implemented for Zimbabwe since we had pre and post treatment data for the same households. The quantile part of the DiD and CiC estimates are reported in Table 6 of the appendix.

Result 1: The multi stakeholder partnership approach in delivering legume seed increased access to seed of improved varieties As shown in Table 5 (Columns 3, 4, and 6 to 8), we find significant improvements in ranges of 27% to 42%, in access to seed of improved bean varieties associated with being resident in intervention communities in Zimbabwe and Burundi compared to residing in nonintervention communities. For example, during the intervention period, promotional campaigns in Zimbabwe stimulated demand for improved variety seed which led to four seed companies coming onboard to supply bean seed. This was accompanied by a 32 to 42% improvement in seed access. Similarly, the number of partners within the bean seed sector in Burundi significantly increased from about 15 in 2014 to 55 in 2018. This led to the widespread availability of seed, thus better access—intervention areas were associated with 27 to 29% more access to seed of improved bean. In Burundi, the project developed partnerships with NGOs[8] (CRS, WV, CAPAD, ADISCO, and UCODE) and deployed various channels and approaches to deliver seed and Integrated Crop Management (ICM) options.

The MSP also impacted on other dimensions of seed access, notably availability, and affordability. Creating synergistic linkages between different seed actors brings seed close to farmers. Our results show a significant reduction in distance to the nearest bean seed market in the community in both Burundi and Zimbabwe. For example, being in an intervention area in Zimbabwe was associated with a 65% reduction in distance to bean seed markets two years post intervention compared to being in a nonintervention area. Bringing seed near to farmers has the potential of stimulating seed demand which then could stimulate seed supply. Furthermore, promoting superior varieties (especially in production traits) and use of inclusive seed packaging appealed to farmers and motivated them to access the seed. More farmers in intervention communities in Zimbabwe were likely to rate the sizes of the seed packs used as suitable.

Access to seed through seed purchases because of project interventions improved in Burundi. Our results show that 42% more farmers in low intervention areas in Burundi were likely to buy the seed they planted

[8] Catholic Relief Services (CRS), World Vision (WV), La Confédération des Associations des Producteurs Agricoles pour le Développement (CAPAD), Appui au Développement Intégral et à la Solidarité sur les Collines (ADISCO), and l'Union pour la Coopération et le Développement (UCODE).

Table 5 Impact of seed system interventions on select seed system performance dimensions

Seed system efficiency dimension	Burundi				Zimbabwe			
	ETE model		METE (Model)		ETE Model		DiD model	CiC model
	POM (Se)	(Se)	Coef. (Se)	Coef. (Se)	POM (Se)	Coef. (se)	Coef. (Se)	Coef. (Se)
	1	2	3 (Low I)[a]	4 (High I)[b]	5	6	7	8
Access to seed (improved varieties) (1 = Yes)	0.60 (0.60)	0.22 (0.60)	0.29*** (0.07)	0.27*** (0.18)	0.14 (0.11)	0.32*** (0.12)	0.34*** (0.05)	0.42*** (0.04)
Log distance to seed market	9.38** (4.72)	− 6.79 (4.17)	− 1.38*** (0.36)	− 0.20 (0.45)	4.39*** (0.51)	− 1.94*** (0.26)	− 0.65*** (0.54)	− 0.62*** (0.21)
Seed market participation (paid for seed used) (1 = Yes)	0.63 (0.81)	− 0.02 (0.82)	0.42*** (0.12)	0.03*** (0.05)	0.83*** (0.12)	0.03 (0.12)	− 0.04 (0.06)	− 0.02 (0.06)
AWAVA (Variety turnover)	12.92 (7.18)	− 3.56 (7.18)	− 1.63 (1.93)	− 4.36** (2.04)	27.72*** (10.06)	− 16.44* (9.91)	− 5.27** (2.58)	− 1.52 (5.52)
Seed price rating (1 = high, 0 = fair)	–	–	–	–	0.56*** (0.11)	− 0.09 (0.11)	− 0.14** (0.07)	− 0.10 (0.06)
Seed pack size rating (1 = suitable)	–	–	–	–	0.64*** (0.09)	0.15* (0.09)	0.14*** (0.06)	0.24*** (0.09)
Perception of seed/variety quality								
Satisfaction with production traits	15.12** (7.61)	− 4.64 (6.39)	− 0.08 (1.04)	1.69*** (0.45)	11.40*** (1.58)	1.71** (0.86)	–	–
Satisfaction with market traits	6.21 (5.28)	3.76 (4.48)	2.75*** (0.16)	0.73*** (0.13)	17.31*** (2.02)	0.04 2.09)	–	–
Satisfaction with consumption traits	10.29*** (2.36)	0.31 (2.00)	0.61 (0.53)	1.11** (0.46)	11.89*** (2.10)	1.66 (2.13)	–	–
Other covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[a] Means the household received a low intensity intervention

[b] Means the household received a high intensity intervention. For the METE model receiving no treatment was taken as the base. For the CiC model, 1000 bootstraps were used. We did not have seed price and seed pack rating data for Zimbabwe

*Significance at 10% level

**Significance at 5% level

***Significance at 1% level. All standard errors are clustered at village level for Zimbabwe and Colline level for Burundi. Various controls used

compared to those in nonintervention areas. The percent was lower (3%) in high-intensive intervention areas in Burundi. We do not find significant evidence that the seed system affected seed purchases in Zimbabwe. However, seed from NGOs, CBOs or other partners, free or on credit seemed to serve the purpose of introducing new variety seed to farmers. Subsequent seed access then happened through conventional mechanisms for example through "seed" from the grain market in Burundi and through seed exchange between farmers in Zimbabwe. This partly shows that the impact of seed systems on seed acquisition indirectly occurs via formal and informal linkages.

Result 2: The MSP improved the quality of seed and varieties supplied For the quality dimension (measured by the perception on quality of seed), in Zimbabwe, results indicate that farmer satisfaction with production traits of the seed/varieties they grew was likely to be higher in intervention areas (Table 5). However, we did not find significant satisfaction ratings for market and consumption traits in Zimbabwe. Furthermore, farmers in high intensity intervention areas in Burundi were likely to report higher satisfaction with all varietal traits and satisfaction levels were highest for production traits probably because they are directly expressed by the seed planted (Table 5). The quality of seed and varieties is important as it stimulates farmers to take up new varieties.

Result 3: Farmers acquired newer varieties that significantly reduced the area weighted variety age (a measure variety turnover) within intervention communities Our analysis shows that the MSP approach was associated with a reduction of the average age of improved varieties grown by 4.4 years among high-intensive intervention groups in Burundi and by 5 years for Zimbabwe beneficiaries. In countries like Ethiopia where stakeholder participation in seed systems is less intense and the presence of entrenched niche market bean varieties, bean varietal turnover has remained high, averaging 19 years (Habte et al. 2021).

Conclusion

There is growing interest in MSP as an innovation to improve farmers' access to seed of improved varieties and accelerate varietal turnover. This interest is fueled by the realization that there are potential synergies for scaling up and out seed dissemination and accelerate seed access if different stakeholders from the private sector (notably seed companies, CBO) and non-profit (i.e. NGOS, government) organizations come together to form a technology dissemination infrastructure. In this study we investigated the effect of MSP on seed access and varietal turnover.

Our findings can be used to infer what would make other legume seed systems more efficient to stimulate productivity growth within the legume subsector in SSA. Our results show that using a multi stakeholder partner-based seed system approach, coupled with production of quality seed of superior varieties, capacity building, and promotion efforts led to enhanced seed access, reduced distance to seed sources, led to higher farmer satisfaction, and high varietal turnover. The study findings confirm that MSP positively and significantly increased seed access even after controlling for confounding factors. In communities with MSP interventions, distance from the farm to seed source reduced and seed packaging was inclusive which enabled different farmers to access it. However, we did not find evidence to suggest that MSP influenced the probability of buying seed from the formal or semi-formal seed systems, implying that access, in some cases, could have been facilitated by free seed distribution. This means that MSP stimulated seed production by private seed producers who sold it to large scale distributors such as NGOs and government programs. The MSP was likely to reduce area weighted age of the variety by between 4 and 5 years, allowing utilization of superior bean varieties by farmers.

This study used a cross-sectional data set with treated and non-treated groups for Burundi and a two-period data set with treated and counterfactual groups for Zimbabwe. Having baseline data and for more periods could have provided a more robust analysis. Nonetheless, our finding provides a good starting point for analyzing the effect of MSPs on bean seed systems which can be generalized to impacts on legume seed systems. Also, we only focused on analysis of select outcomes to inform the impact of the MSP led bean seed system. This was because of data limitations which constrained us from using all seed system efficiency dimensions. Future research could provide a more complete and comprehensive analysis of the performance of a seed system that is organized as a MSP and or is following similar interventions.

Appendix

See Table 6.

Table 6 Quartile DiD and CiC estimates of seed system intervention effects on seed system outcomes (ZIMBABWE)

	Quartile regression estimates				
	0.1	**0.25**	**0.50**	**0.75**	**0.9**
Change in Change					
Access to seed	− 0.007 (0.011)	− 0.005 (0.008)	0.001 (0.369)	0.962*** (0.036)	0.861*** (0.045)
Log distance (km)	− 1.749** (0.700)	− 0.777*** (0.255)	− 0.541** (0.249)	− 0.037 (0.406)	0.097 (0.336)
Seed market participation (paid for seed used)	0.434 (0.369)	− 0.012 (0.037)	− 0.066 (0.050)	− 0.082 (0.078)	− 0.166 (0.102)
Variety turnover	− 4,176* (2.277)	− 1.168 (1.791)	1.930 (3.431)	3.431 (2.793)	12.149* (6.932)
Qquartile Difference In Difference					
Access to seed	0.013 (0.013)	0.009 (0.009)	0.012 (0.368)	0.973*** (0.018)	0.033 (0.331)
Log distance (km)	− 1.686** (0.677)	− 0.564** (0.224)	− 0.384 (0.279)	− 0.230 (0.357)	0.151 (0.215)
Seed market participation (paid for seed used)	− 0.021 (− 0.254)	0.218** (0.112)	− 0.050 (0.055)	− 0.073 (0.059)	− 0.325** (0.128)
Variety turnover	− 7.325** (3.007)	− 0.695*** (2.299)	− 3.741* (2.038)	− 1.486 (2.978)	12.061*** (3.515)

*Significance at 10% level; **Significance at 5% level; ***Significance at 1% level

Abbreviations

ABC	Alliance of bioversity international and the international center for tropical agriculture
ADISCO	Appui au Développement Intégral et à la Solidarité sur les Collines,
ATET	Average treatment effect on the treated
AWAVA	Area weighted age of the variety
CAPAD	La Confédération des Associations des Producteurs Agricoles pour le Développement;
CBOs	Community based organizations
CIAT	Center for international tropical agriculture
CiC	Change in change
CRS	Catholic relief services
DiD	Difference in diffrence
DR&SS	Department of research and specialist services
ECABREN	East and Central Africa Bean Research Network;
ETE	Endogenous treatments effects
FAO	Food and agriculture organization
ICM	Integrated crop management
ISABU	Institut des Sciences Agronomiques du Burundi
KEPHIS	Kenya plant health inspectorate service
METE	Multinomial endogenous treatments effects
MSPs	Multi stakeholder partnerships
NARS	National agricultural research systems
NGO	Non governmental organization
NRRI	National Rice Research Institute
ONCCS	National office of control and seed certification
PABRA	Pan African Bean Research Alliance
QDS	Quality declared seed
SABRN	South African Bean Research Network
SDC	Swiss agency for development and cooperation
WECABREN	West and Central Africa Bean Research Network
WV	World vision
UCODE	L'Union pour la Coopération et le Développement;

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Author contributions
PA: Conceptualization, Methodology, Writing—Original Draft, Visualization, writing-review and editing, formal analysis, Project administration, and interpretation. EK: Conceptualization, Methodology, Data Curation, Writing—Original Draft, writing-review and editing, formal analysis, Validation, investigation, Project administration, and interpretation. All authors read and approved the final manuscript.

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Availability of data and materials
All data supporting the article can also be accessed directly from the corresponding author upon reasonable request.

Declarations

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Not applicable.

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Authors declared that they have no competing of interest.

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References

AGRITEX. Second round crop and livestock assessment report ministry of agriculture, mechanisation and irrigation development Zimbabwe. Afr Crop Sci J. 2015;25(2):221.

Assefa T, Rubyogo JC, Sperling L, Amsalu B, Abate T, Deressa A, Kirkby FR, Buruchara R. Creating partnerships for enhanced impact: bean variety delivery in Ethiopia. J Crop Sci Soc Ethiopia. 2006;12:1–19.

Athey S, Imbens W. G. Identification and inference in nonlinear difference-in-differences models on JSTOR. Econometrica. 2006. https://www.jstor.org/stable/3598807. Accessed: 05th Dec 2021.

Atlin GN, Cairns JE, Das B. Rapid breeding and varietal replacement are critical to adaptation of cropping systems in the developing world to climate change. Glob Food Sec. 2017;12:31–7. https://doi.org/10.1016/J.GFS.2017.01.008.

Bararyenya A, Ntamavukiro A, Simbashizubwoba C, Gildemacher P. ISSD Briefing Note-September 2012 Burundi Seed Sector Assessment. 2012. http://www.wageningenportals.nl/sites/default/files/resource/burundi_seed_sector_assessment_2012.pdf. Accessed 17 Dec 2021.

Barriga A, Fiala N. The supply chain for seed in Uganda Where does it go wrong. World Develope. 2020;130:104928.

Christopher, M. Logistics and supply chain management. 2011. www.pearson-books.com. Accessed: 25th Oct 2021.

Demelash B. Common bean improvement status (*Phaseolus vulgaris* L) in Ethiopia. Adv Crop SciTechnol. 2018;6(2):1–6. https://doi.org/10.4172/2329-8863.1000347.

Dontsop Nguezet, P. M, Manyong, V. M, Abdoulaye, T, Alene, A, Amato, M. S, Ainembabazi, J. H, Mignouna, D. B, and Okafor, C. Non-farm activities and adoption of improved cassava and beans varieties in South-Kivu, DR Congo. Tropicultura. 2016. https://cgspace.cgiar.org/handle/10568/77858. Accessed: 29th Aug 2022.

FAO. Promoting the growth and development of smallholder seed enterprises for food security crops best practices and options for decision making. 2010. https://www.fao.org/3/i1839e/i1839e00.pdf. Accessed: 30th January 2022.

FAO. Seed secuity assessment: a practitioners guide. 2016. https://www.fao.org/3/i5548e/i5548e.pdf. Accessed: 25 Oct 2021.

Habte, E, Katung, E, Yirga, C, Amsalu, B, Ratz, B, Mukankusi, C, Rubyogo, J. C, and Sebatta, C. Adoption of common bean technologies and its impacts on productivity and household welfare in ethiopia: lessons from tropical legumes project. 2021. localhost:8080/xmlui/handle/123456789/3476. Accessed 18th August 2021.

Hamazakaza P, Katungi E, Ryes B, Maredia MK, Muimui KK, Ojara M. Assessing access and adoption of common bean improved varieties in Zambia. PABRA Research Technical Report. 2014. https://cgspace.cgiar.org/bitstream/handle/10568/59768/ZAMBIA%20ADOPTION%20REPORT%20JAN%2020152.pdf?sequence=4. Accessed 29 Aug 2022.

Imbens GW, Wooldridge JM. Recent developments in the econometrics of program evaluation. J Econom Lit. 2009;47(1):5–86. https://doi.org/10.1257/JEL.47.1.5.

Iorlamen T, Iyorkaa N, Omoigui LO, Ademulegun T, Kamara AY, Solomon R, Iorlamen T, Omoigui LO, Kamara AY, Garba U, Iyorkaa N, Ademulegun T,

Solomon R. Developing sustainable cowpea seed systems for smallholder farmers through innovation platforms in nigeria: experience of tl iii project enhancing smallholder farmers. Access Seed of Improv Legume Var through Multi-Stakeholder Platf. 2021. https://doi.org/10.1007/978-981-15-8014-7_9.
Johnson NL, Pachico D, Wortmann CS. The impact of CIAT's genetic improvement research on beans. In: Eveson RE, Gollin D, editors. Crop Variety improvement and its effects on productivity: the impact of International Agricultural Research. Wallingford, UK: CAB International; 2003. p. 257–274. https://doi.org/10.1079/9780851995496.0257
Katungi EM, Larochelle C, Mugabo JR, Buruchara R. The effect of climbing bean adoption on the welfare of smallholder common bean growers in Rwanda. Food Security. 2018;10(1):61–79. https://doi.org/10.1007/S12571-017-0753-4.
Katungi, E, Karanja, D, Wozemba, D, Mutuoki, T, and Rubyogo, JC. A cost-benefit analysis of farmer based seed production for common bean in Kenya. African Crop Science Journal. 2011. https://www.cgspace.cgiar.org/handle/10568/96958. Accessed: 18th Aug 2021.
Katungi, E. M, Magreta, R, Letaa, E, Chirwa, R, Dambuleni, K, and Nyamwaro, S. S. Adoption and impact of improved bean varieties on food security in Malawi. 2017a. https://www.cgspace.cgiar.org/handle/10568/96958Accessed: 29th Aug 2022.
Katungi, E, Mutua, M, Mutari, B, Makotore, W, Kalemera, S, Maereka, E, Zulu, R., Birachi, E, & Chirwa, R. Improving bean production and consumption in zimbabwe baseline report. 2017b. https://core.ac.uk/outputs/132691630. Accessed: 06th July 2022.
Katungi, E, Nduwarigira, E, Ntukamazina, N, Niragira, S, Mutua, M, Kalemera, S, Onyango, P, Nchanji, E, Fungo, R, Birachi, E. A, Rubyogo, JC, and Buruchara, R. A. Food security and common bean productivity: Impacts of improved bean technology adoption among smallholder farmers in Burundi. 2020. https://cgspace.cgiar.org/handle/10568/109119. Accessed: 18th Aug 2021.
KEPHIS. National Crop Variety List—Kenya. 2021. https://www.kephis.org/images/pdf-files/UPDATED2020AugustNATIONALVARIETYLIST1.pdf. Accessed: 06th July 2022
Larochelle C, Alwang J, Norton GW, Katungi E, Labarta RA. Impacts of improved bean varieties on poverty and food security in Uganda and Rwanda. Crop Improv Adopt Impact Improv Variet Food Crops Sub-Saharan Afr. 2015. https://doi.org/10.1079/9781780644011.0314.
Larochelle, Catherine, Asare-Marafo, D., Birol, E., & Alwang, J. Assessing the adoption of improved bean varieties in rwanda and the role of varietal attributes in adoption decisions. 2016. https://www.harvestplus.org/wp-content/uploads/2016/09/HarvestPlus_WorkingPaper25.pdf. Accessed: 29th Aug 2022.
Letaa E, Kabungo C, Katungi E, Ojara M, Ndunguru A. Farm level adoption and spatial diffusion of improved common bean varieties in southern highlands of Tanzania. African Crop Sci J. 2015;23(3):261–77.
Mabaya E, Mujaju C, Nyakanda P, Mugoya M. Zimbabwe Brief 2017. Afr Seed Access Index. 2017;50:63.
B Edward Mabaya Bararyenya Ernest Vyizigiro A, Waithaka Mainza Mugoya, M. Kanyenji Krisztina Tihanyi By Edward Mabaya Astère Bararyenya Ernest Vyizigiro Michael Waithaka Mainza Mugoya George Kanyenji Krisztina Tihanyi, G. 2021 Burundi Country Report 2021. The African Seed Access Index https://doi.org/10.2004/AG.ECON.317017
Maereka, E K, Makate, ., Chataika, B. Y. E, Mango, N, Zulu, R. M, Munthali, G. T, Amane, M. I. V, and Chirw, R. M. Estimation and characterization of bean seed demand in angonia district of mozambique. 2015. https://cgspace.cgiar.org/handle/10568/117574. Accessed: 29th Aug 2022
Maereka, Enock Kuziwa. An estimation of grain legume seed system efficiency in developing countries. creative components. 2020. https://lib.dr.iastate.edu/creativecomponents/530. Accessed 25th Oct 2021
Marcho C, Records AR, Lapitan NLV. Transforming crop breeding in the developing world. CSA News. 2020;65(7):31–3. https://doi.org/10.1002/CSAN.20199.
Maredia MK, Reyes BA, Manu-Aduening J, Dankyi A, Hamazakaza P, Muimui K, Rabbi I, Kulakow P, Parkes E, Abdoulaye T, Katungi E, Raatz B. Testing alternative methods of varietal identification using dna fingerprinting: results of pilot studies in Ghana and Zambia. Food Secur Int Develop Working Papers. 2016. https://doi.org/10.22004/AG.ECON.246950.
Mastenbroek A, Otim G, Ntare BR. institutionalizing quality declared seed in Uganda. Agronomy. 2021. https://doi.org/10.3390/AGRONOMY11081475.
Monyo, E. S. Seven seasons of learning and engaging smallholder farmers in the drought-prone areas of sub-Saharan Africa and South Asia through tropical legumes, 2007–2014. 2016. https://repo.mel.cgiar.org/handle/20.500.11766/6714. Accessed: 18th August 2021
Munyaka N, Mazarura U, Mvumi B. A compelling case for seed enterprises as a tool for rural development in the smallholder farming sector. Afr J Rural Dev (AFJRD). 2017;2(2):199–212. https://doi.org/10.22004/AG.ECON.262838.
Muthoni RA, Andrade R. The performance of bean improvement programmes in Sub Saharan African from the perspective of varietal output and adoption. In: Walker TS, Alwang J, editors. Crop improvement, adoption and impact of improved varieties in food crops in Sub-Saharan Africa. 2015. https://doi.org/10.1079/9781780644011.0148
Nduwarugira E, Ntukamazina N, Nijimbere B, Niyoyankunze JM, Ndabashinze B, Nyetereye P, Ndikumana J, Nsengiyumva A, Nshimirimana I, Emerusenge E. Catalogue of released common bean varieties in Burundi. 2nd ed. Burundi: Burund Institut des Sciences Agronomiques du Burundi; 2020.
NRRI. released varieties—National rice research institute (NRRI). 2021. https://icar-nrri.in/released-varieties/. Accessed: 30th Jan 2022.
Ojiewo CO, Omoigui LO, Pasupuleti J, Lenné JM. Grain legume seed systems for smallholder farmers. Perspect Success Innov. 2020. https://doi.org/10.1177/0030727020953868.
Pan African Bean research alliance. PABRA Database. 2022. https://cgspace.cgiar.org/handle/10568/66451. Accessed: 14th Jan 2022.
Rubyogo J-C, Sperling L, Muthoni R, Buruchara R. Bean seed delivery for small farmers in sub-saharan Africa. Power Partnersh. 2010. https://doi.org/10.1080/08941920802395297,23(4),285-302.10.1080/08941920802395297.
Rubyogo J-C, Akpo E, Omoigui L, Pooran G, Chaturvedi SK, Fikre A, Haile D, Hakeem A, Monyo E, Nkalubo S, Fenta B, Binagwa P, Kilango M, Williams M, Mponda O, Okello D, Chichaybelu M, Miningou A, Bationo J, Kalemera S. Market-led options to scale up legume seeds in developing countries: experiences from the tropical legumes project. Plant Breeding. 2019;138(4):474–86. https://doi.org/10.1111/PBR.12732.
StataCorp LLC. Stata Base Reference Manual Release 17. College Station, TX: Stata press, 2021. https://www.stata.com/manuals/r.pdf. Accessed 12 Jan 2022.
Tebeka YA, Katungi E, Rubyogo JC, Sserunkuuma D, Kidane T. Economic performance of community based bean seed production and marketing in the central rift valley of Ethiopia. Afr Crop Sci J. 2017;25(2):189–205. https://doi.org/10.4314/acsj.v25i2.5.
Varshney RK, Ojiewo C, Monyo E. A decade of tropical legumes projects: development and adoption of improved varieties, creation of market-demand to benefit smallholder farmers and empowerment of national programmes in sub-Saharan Africa and South Asia. Plant Breeding. 2019;138(4):379–88. https://doi.org/10.1111/PBR.12744.

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