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Seed systems and climate change adaptation

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Summary of key points

- Climate change has multiple and diverse impacts on smallholder farming systems. A singular focus on crop breeding is not a silver bullet for farmer adaptation.
- The current performance of seed systems serving smallholder farmers is insufficient. They limit smallholders benefitting from the know-how of both private breeding companies and public research institutes.
- A system-shift towards a seed-user centric approach is critical. The interaction between seed users and researchers in breeding and selection needs to be intensified to deliver a much broader portfolio of varieties that respond to a continuously changing set of circumstances.
- Early generation seed production by public research organizations alone makes the seed system vulnerable. It is essential that national legislation allows for - and the national seed policy promotes- EGS production by private entities.
- Large numbers of 'best-bet' varieties need to be tested rapidly and validated using large-scale, local data collected from farmers and their fields. This will require the reform of variety registration regulation in many countries.
- National seed sector regulation and policy needs to be such that it accommodates both stakeholder collaboration and competition. Maintaining the balance in engagement between public and private actors requires effective seed sector governance.

Box 1: Improved Millets

Over the last decades, millets have fallen out of favour in many countries (Bitzer et al., 2023). Major reasons are the low productivity compared to maize and sorghum, the cumbersome processing, and the shift in household diets, who over time are favouring rice, wheat and maize based dishes over millet dishes.

Millets are currently gaining renewed attention for their resilience in unreliable rainfall conditions, low soil fertility, high salinity and low soil pH. In addition they have a short growing season, and a favorable nutritional value compared to other grain staples. The recognition of the nutritious values and the strongly risen food prices offer renewed local and international market opportunities for millets (Bitzer et al., 2023).

To make the most out of millets as a resilient crop with renewed market opportunities, which can support farmers in adaptation to climate change, a diverse portfolio of OPV and hybrid varieties needs to be made available to farmers. This will require investments in crop improvement. The appetite of the private sector to invest in millet improvement is limited. Nonetheless ICRISAT in India managed to mobilize (private sector co-investment in pre-competitive crop improvement efforts. The private sector interest was limited, however, to hybrids for high volume markets with reliable rainfall (Nagajaran, 2006).

To radically increase the offer of highly productive millet varieties to the diversity of agro-ecologies and socio-economies where they can contribute to climate change adaptation requires a major additional effort, which can only be initiated with public resources, and at best be complemented with private sector resources, as profitability of millet seed business is only modest, and concentrated in few main and low-risk production areas.

Introduction

Farmers globally are facing the challenges of a changing climate. Smallholder farmers in low and middle income countries are disproportionally affected by the effects of climate change (Morton, 2007; Bukchin-Peles & Fishman, 2021). Climate change affects smallholder farmers in rainfed production systems most significantly through less rainfall and less reliable rainfall patterns.

Improved crop varieties are often proposed as one of the most promising pathways for smallholder producers to adapt to climate change (Atlin et al, 2017; Etten et al., 2019). This paper explores what would be required from seed systems to assure smallholder farmers benefit from adapted cultivars to adapt to climate change.

To do so, the paper addresses the promise of variety improvement in adapting to climate change from a smallholder farmer, seed-user perspective. The paper considers the place of improved varieties within the adaptation efforts of smallholder producers. It reflects on the challenges that are hindering the potential of adapted varieties for smallholder farmer climate change adaptation. A seed chain analysis is used to identify what actions are needed to assure smallholder producers benefit from improved varieties as one of the tools at their disposal to adapt to climate change.

Improved varieties adaptation strategy in perspective

Taken at face value, climate change constraints for smallholder farmers may be hastily reduced to challenges with drought, to which a common response would be the introduction of 'drought tolerant varieties'. Unfortunately, climate change challenges faced by smallholder farmers are multi-dimensional and as a result, also the desired variety traits for climate change adaptation are non-singular.

It is not simply reduced rainfall that smallholder farmers are grappling with. In addition to less rain, (and in some cases, much more rain) there is a change in seasonal rainfall patterns, often resulting in a shorter productive season. Also, the ability to predict the start as well as the end of the season reduces, which has a major impact on farming. The distribution of rain over the rainy season is another variable that is becoming more stochastic and thus less reliable.

Along with changes in rainfall there are increases in temperature, which heightens the process of evapotranspiration of crops, exacerbating the effect of less and less-reliable rainfall. Higher temperatures also affect crop growth and development in different manners, such as pollination, growth rate, grain or tuber development and growth period (Hatfield & Prueger, 2015). Rising temperatures also affect the agro-ecology, changing the pest, disease and weed pressures farmers have to cope with. Finally, there are the effects on the soil, such as increased soil organic matter decomposition and higher chances of salinization associated with higher evapotranspiration and a possible negative water balance.

Responding to the threats posed by drought, changing rainfall patterns and increasing temperature is a daunting task for crop breeders. Variety traits that can contribute to climate resilience for smallholder farmers are drought tolerance, heat tolerance, a better developed, deeper, rooting system, a shorter growing period, and tolerance to salinity (Atlin et al, 2017). A major breeding challenge is that these traits are not found on a single major gene, but result from the combined small effects of multiple genes, making targeted breeding cumbersome, as is described by Atlin et al. (2017) for rice, leading them to conclude that a more realistic approach is to assure a steady stream of incrementally improved cultivars.

Farmers have other strategies they apply for climate change adaptation, with which variety choice needs to be aligned. Farmers will naturally adapt their water management, cropping calendar, crop choices, soil management and crop protection practices, further adding to the complexity of predicting which variety farmers would desire to replace their current choice.

Finally, variety choice is not a strict technical decision to use the best-performing variety under the prevailing agro-ecological conditions. At least as important is the 'fit' of the variety with the household economic and household food security objectives. Rural households in Africa derive two-thirds of their income from agricultural production (Christiaensen, 2017). Even among the poorest and smallest landholders in Malawi, Tanzania and Uganda, market participation is 90% (Carletto et al., 2017), demonstrating that responding to market demand is a major consideration. The balance between household food security and income objectives is household specific, and subject to intra-household dynamics (Anonymous, 2018). The market not only affects variety traits related to market and consumer demand, but also interacts with the timing of production, as market-oriented farmers seek to time their harvest with higher market prices.

A smallholder farmer needs to weigh many factors in his or her choice of a variety, including the cropping calendar, food and nutrition security objectives, the farm agro-ecology, and the market. Uncertainties resulting from climate change add to the already complex mix of factors to consider.

Considering these social, economic and bio-physical dynamics, it quickly becomes clear that there are clear limits to crop breeding as a silver bullet for climate change adaptation by smallholder farmers. Variety improvement can make important contributions, but breeders cannot be expected to rapidly select 'winning' varieties that take the smallholder farming system by storm and alleviate the challenge they face.

Climate change adds an additional dynamic to the traits desired in cultivars, making the tasks of both seed users and breeders significantly more difficult. The result is a demand for more diversity in cultivars. This adds not only complexity for breeders, but also poses challenges for an effective and efficient regulatory variety selection process, seed marketing, and agricultural advisory services.

What is required in response to an increasingly complex and diverse set of demands is a seed-user centric approach. Such an approach is a radical departure from the linear notion that desired variety traits can be predicted by well-informed scientists in private breeding companies and public research organizations. It requires a systems shift, building and structuring permanent collaboration between local seed users, public breeders, and private seed companies with the aim of dramatically accelerating the process of responsive breeding, selection and variety renewal. This will broaden the range of available crop varieties and increase the variety replacement rate to respond to a continuous change of circumstances.

Seed sector performance needs

A broader crop variety portfolio and faster variety replacement necessitates systemic changes to the seed chain serving smallholder producers. To discuss the seed system changes required, a seed chain analysis is presented (adapted from Audet-Bélanger et al., 2013) which disaggregates the seed chain in operations from breeding to seed use (See Table 1).

Breeding

The role of private breeding companies as well as public breeders is to integrate traits relevant for smallholder climate change adaptation into candidate varieties whilst also respecting market and social preferences. In particular, low-profit seed crops such as pulses, vegetatively propagated crops as sweet potato and cassava as well as open pollinated grains like sorghum and millet require attention by breeders from public research organisations (Gildemacher et al, 2017). Cash crops and high-value commodities, such as hybrid maize, hybrid vegetables and to a lesser extent potatoes, allow for larger financial margins in the seed chain, which makes private sector investment in breeding more attractive. International public research can contribute by engaging in pre-competitive genetic resource conservation and characterization.

Smallholder farmers do play a role in the improvement of Open Pollinated Varieties (OPVs), most often through field selection, rather than deliberate crossing. However, it is unlikely that the large genetic gains required for climate change adaptation can be realized by farmer breeding efforts.

Variety selection

A significant change in practices is required in variety selection. Current selection processes take far too long. Consequently, variety selection typically screens for varieties with good performance across different environments and agro-ecologies, with the assumption that this will result in a narrow set of widely-appreciated varieties. To provide a service better tailored to the growing diversity demanded by smallholder farmers to respond to climate change, a broader set of varieties, accompanied by adequate information and the opportunity by farmers to validate local performance is desired. The notion that researchers can deliver a few star varieties that can cater to the needs of many is false.

A changing environment requires a system able to innovate rapidly. This requires input from a diversity of actors, but most importantly by the end user, the smallholder farmer. A ‘best-bet’ preselection of candidate varieties can be availed by private breeding companies and public breeders, but the ultimate selection of local ‘best-fit’ varieties is better organized through local validation and market mechanisms, rather than organized multi-locational trials initiated by researchers.

The fear that farmer self-selection from a large portfolio of candidate varieties can go horribly wrong under-estimates the entrepreneurial dynamic and risk-management capacity of smallholder farming communities.
Farmers seek out and experiment with new varieties and other technologies before going all-in with a well-weighed assessment of the risks asscoiated with the full adoption of a novel variety.

To assure rapid local screening of candidate varieties for local fit, another system change is required. The ‘human resource infrastructure’ of farmer / seed producer / seed trader collaboration needs to be established. Selected farmers and local seed producers / seed traders need to integrate candidate variety screening as a routine part of their business operation, fueling constant variety replacement. Citizen science approaches using crowd-sourcing of data have shown to be powerful methods for realizing accelerated and locality-specific selection of high performing varieties from larger sets of candidate varieties (Van Etten et al., 2019).

Initially, this local collaboration between seed producers, seed traders and farmers may need to be actively facilitated by professional agricultural development intermediary organizations such as NGOs or knowledge institutes. The collection and analysis of data at a larger scale will require researcher involvement.

Box 2: Pre-ordering climate-resilient bean seed in Burundi

Common beans are an important crop in Burundi and most smallholders cultivate it for own consumption, but there is limited incentive to produce for the market. The bean seed system is still mostly informal, with farmers recycling own seed or exchanging with neighbours. However, there are good indications that this is changing.

The Pan-Africa Bean Research Alliance (PABRA), in collaboration with the Institut des Sciences Agronomiques du Burundi (ISABU) – the Burundi National Agricultural Research institute – has released 24 climate-resilient and biofortified varieties since 2015 (Onyongo, 2022). Over the same period, a complementary project, Private Seed Sector Development (PSSD) Burundi and its antecedent worked with ISABU and government partners to develop a seed preordering system. This allows ISABU to deliver the desired varieties in the required quantities and at the right time. Private seed entrepreneurs place a timely order with ISABU and advance 10% of the cost. This efficient public-private model has seen the number of seed entrepreneurs producing certified bean seed double between 2017 and 2022, with the quantity delivered by ISABU increasing ten-fold (Smolders, 2023). Varietal turnover has also increased, with 91% of the bean seed produced in 2020 being cultivars less than 10 years old (Onyongo, 2022).

Private seed companies may be able to assure this role in high-profit seed crops, whilst for lower-profit seed crops national and international public research organizations have an important role to play.

The end-goal of variety selection should not be the selection, beyond any doubt, of the very best-performing varieties, but rather the selection of a broader portfolio of valuable varieties for farmers to choose from, based on their assessment of the agro-ecological fit, market and home consumption objectives.

Early generation seed production

A broader portfolio of varieties to cater to a more diverse demand complicates the early generation seed production system. A demand inventory system, based on the market intelligence of local seed multipliers and seed traders becomes indispensable. A pre-ordering system of EGS demand articulation, substantiated by partial pre-financing by seed entrepreneurs has proven effective in Burundi. EGS production for high-profit seed crops is often catered for by private breeding or seed companies, of international level, or national level.

EGS production is particularly challenging for low-profit seed crops. Public investment is required to build financially sustainable and reliable EGS production business models. Private seed companies can get engaged in EGS production of low-profit seed crops, but the financial viability of their engagement may have to be guaranteed through public subsidy, co-funding or market guarantees. EGS production by public research organizations alone makes the seed system vulnerable to the weaknesses of public sector financial management and planning and will make the offering of a larger portfolio of varieties to cater for increased diversity of demand unlikely. It is essential that national legislation allows for - and the national seed policy promotes- EGS production by private enterprises.

Seed multiplication

Seed multiplication opportunities and challenges do not principally change with a broadening of the variety portfolio needed to address climate change adaptation. The seed multiplication operation will become slightly more complicated if more variety choice is offered.

High-profit seed production can benefit from the economies of scale and know-how of international and national private seed companies, which have the flexibility to strike the right balance between centralized multiplication with tight quality assurance and local onward multiplication situated closer to end-users.

For low-profit seed crops the inclusion of varieties better adapted to climate change challenges can actually strengthen the functioning of seed multiplication and marketing systems. For these crops, demand for seed is often driven by the desire to obtain better adapted varieties becoming available. More rapid innovation of the variety portfolio can make seed systems of low-profit seed function better as a result of stronger demand. . Low-profit seed remains more likely to be driven by local seed multipliers, rather than national and international seed companies.

Seed marketing and dissemination

Seed marketing and dissemination requires an additional efforts to ensure smallholders will be able to benefit from improved varieties to adapt to climate change. Offering a broader choice of varieties means investment in crop demonstrations and the ability to provide the needed information for smallholder farmers to make a best-fit choice for which cultivars to experiment with on their own farm. The private seed retailer, either a specialized seed trader or a local seed producer retailing his or her own produce, will need to engage more with local clientele to promote a wider range of available seed. In case of limited sales volumes, which is possible for low-profit seed and in more remote localities, demonstration and information supply may require a significant co-investment from public or international development sector sources.

Seed use

Smallholder farmers are unlikely to adopt a variety without first experimenting on their own farm. They observe and judge variety performance relative to their household objectives. Researchers have the mandate to collate, structure and analyze the results of farmer experimentation with new varieties to understand the performance of newly emerging varieties under diverse circumstances. This can provide continuous feedback for the purpose of improving breeding and variety selection.

Assuring seed is available in affordable, small packages will incentivize farmer experimentation. To reap the maximum benefits from using improved varieties, only investing in quality seed is not enough. Significant benefits can be gained from associated better crop husbandry practices. Agricultural advisory service providers have the mandate to support farmers in their experimentation with improved varieties and associated crop husbandry practices. Agricultural advisors can be public extension officers, local private service providers, agents of seed and input providers, or agents of farmer organizations or local NGOs.

For high-profit seed crops a modest effort can be expected from the seed producer or trader to support the seed client. For low-profit seed crops this is only likely if additional development budget is available to offset the costs of providing additional cultivation advice from seed producers or traders.

However, this engagement is of paramount importance to assure performance feedback from seed users. Local seed producers and traders can play valuable roles as intermediaries in the communication between seed users and private and public breeders.

registration and marketing. The anchoring of the 'breeders' exemption', as stipulated under the 1991 act of the UPOV convention (UPOV, 2009) is important for rapid incremental variety portfolio innovation.

Box 3: Community seed banks

Community seed banks are one way to address some of the improvements needed on the pathway towards a seed-user centric seed chain. A community seed bank is locally governed and managed seed repository were a diversity of varieties are safeguarded, often by farmer groups or cooperatives. There are different organizational forms which are often informal, but in several countries well established seed banks gain support and legal recognition, for example in South Africa, India, Uganda or Mexico (Vernooy et al., 2016, Vernooy et al. 2020).

The varieties that are conserved, stored and revitalized in a community seed bank often include local varieties that are adapted to local circumstances, but is not necessary limited to them. The conservation, storage and revitalization of a diversity of seeds contributes to several objectives: it enhances agricultural biodiversity, it contributes to the availability of varieties with different traits that are locally adapted so farmers can respond to different objectives and circumstances, it provides access to seeds for farmers. As such, the available genetic diversity in community seed banks is believed to have the potential to increase resilience of farmers, and mitigate threats posed by climate change, pests and diseases (Vernooy, 2016, Porcuna-Ferrer et al. 2020).

Enabling environment – seed policy and regulation

To facilitate continuous incremental innovation of the variety portfolio available to smallholder producers, seed regulation may need to be updated. Seed regulation and a seed regulatory body with a client-oriented approach and mentality, rather than a policing mentality is paramount.

A competitive environment is required in which seed companies are challenged to innovate their portfolio to maintain their market and profits. Assurance of the protection in the seed law of breeders' rights is essential for private sector investment in breeding and selection, variety

Easy import of and full-field use of candidate varieties is required for large-scale localized testing of their performance. Unless there are significant phytosanitary risks for a specific crop, the benefits of rapid broad testing in practice with farmers outweigh the risks of quarantine disease importation. There are much larger quantities of commercial seed trading internationally, so there is no justification to subject material of candidate varieties to more stringent import regulation than commercial seed. For commercial seed, import restriction for other reasons than significant phytosanitary concerns harm the innovation capacity of the seed system, and hurts the interests of smallholder producers. In particular, tendencies to use import barriers

to stimulate local seed sector development are to be avoided, as they do not contribute to the desired competitive environment in which the international breeding and selection know-how becomes locally available to smallholders to benefit from to adapt to climate change.

To promote broad variety catalogues that offer farmers the opportunity to tailor variety choice to their local needs, variety registration needs to be kept as light as possible. Other than for the purpose of registration for breeders rights protection, there are no significant arguments to limit variety registration. The sometimes-voiced fear that farmers will be overwhelmed with too many varieties if registration is too light is going against the principle to offer farmers as individual entrepreneurs the opportunity to choose. The principle that a new variety needs to broadly tested to proof to be 'better' than the already registered varieties is based on the flawed assumption that there is a universal way to judge the quality of a variety. A rapid screening of candidate varieties and a low barrier for variety registration will promote farmer experimentation, contributing to rapid incremental variety portfolio innovation. The acceptance of data from structured crowd sourcing of data by 'citizen science' method for variety registration can reduce barriers and improve the local fit of registered varieties (van Etten et al., 2019).

To protect the reputation of seed companies and maintain the trust of seed users in the quality of packaged seed from formal sources, quality assurance is important. Much emphasis is often given to seed certification at the level of seed production, with varying levels of success. This is, however, not complete without quality assurance at retail level – for example efforts to stamp out counterfeit seed- which may even be more urgent and cost-effective compared to the seed certification at seed producer level.

Seed sector governance

The creation of a seed system supporting the rapid incremental variety improvement to assist farmers adapt to climate change requires an intensification of collaboration amongst seed sector actors. For variety selection in particular, intensive collaboration is needed. To assure continuous feedback on variety performance and for localized demand articulation, collaboration between seed users and commercial local, national and international seed actors is required. Public sector and development actors have a strong added-value to private sector actors in the low-profit seed crops. Maintaining the right collaboration and balance in engagement between public and private actors requires seed sector governance. For conflict resolution, pre-competitive collaboration as well as solving regulatory constraints, governance of the seed sector is critical. Different stakeholders need to have a credible representation. For effective seed sector governance there needs to be a relatively neutral convener of stakeholders.

Conclusion

Improved crop varieties can make an important contribution to climate change adaptation by smallholder farmers. It must be acknowledged, however, that improved varieties are just one of the multiple inputs that smallholder producers require. The expectation that crop breeders will deliver climate change adaptation solutions in the form of few broadly-applicable varieties is unrealistic. For smallholder farmers to access improved varieties as a tool in climate change adaptation, incremental innovation within the variety portfolios is required. Adding traits relevant for climate change mitigation to variety portfolios makes demand more diverse, and responding to this diverse demand by breeding and selection a more complex task.

The current performance of seed systems serving smallholder farmers does not suffice. Worse, it often constitutes a barrier for smallholders to benefit from the potential of the global know-how and capacities of private breeding companies and public research institutes. To assure that the performance of the seed system is not the limiting factor, the interaction between seed users and researchers in breeding and selection needs to be intensified. Testing and selection of candidate varieties originating from private and public breeding needs to become a routine part of the business of local seed producers and selected seed users. Larger numbers of best-bet candidate varieties need to be tested quickly at seed user level, for rapid decision making and registration, validated by large-scale, local data. This will require the reform of variety registration regulation in many countries.

To ensure that farmers make informed choices, seed producers, seed traders and agricultural advisory service providers need to collaborate to support producers through variety demonstrations and with information to differentiate between varieties. Farmers' on-farm experimentation should be facilitated by the availability of small trial packages, to test the fit of the varieties and associated crop husbandry recommendations within their socio-economic and agro-ecological reality. This accommodates informed decision-making on variety adoption.

The insights of seed users regarding variety fit is highly valuable for the variety portfolio innovation process. Collecting these insights in a structured quantitative and semi-structured qualitative manner is important to assure constant input into an incremental, responsive breeding process. Local seed producers and traders as well as researchers need to play a permanent intermediary role between seed users and breeding and selection.

Seed sector regulation and governance needs to be such that it accommodates both stakeholder collaboration and competition. Through the intensification of seed-sector actor engagement for variety selection and marketing, built from a local seed-user perspective, and with as its basis seed-user – local seed entrepreneur collaboration, a seed system can be created that fosters rapid incremental variety portfolio innovation. In such a seed system smallholder farmers can quickly benefit from progressive gains made by private and public breeding to offer varieties with traits that support their adaptation to climate change.

Table 1: Seed chain analysis identifying improvements and actor roles to assure improved varieties contribute to smallholder climate change adaptation

Seed chain component	*Actors*	*Observations*
Breeding		Identify climate change adaptation relevant traits to integrate in broad selections of candidate varieties
	Private breeding companies	Focus on high-profit seed crops
	Public breeding	Focus on low-profit seed crops (OPVs, VPCs others than potato) Pre-competitive genetic resource conservation and characterization
Variety selection		Faster change in circumstances requires faster variety change Accelerated local selection needed of varieties serving the increasing diverse demand of seed users and market Larger portfolio of variety options required to cater for more diverse needs
	Private breeding companies	Selection of localized variety portfolios of high-profit seed in collaboration with local actors
	Public breeding	Selection of localized variety portfolios of low-profit seed in collaboration with local agents
	Seed production companies	Implement local rapid screening of candidate varieties to establish local desired portfolios of varieties
	Agricultural research	Structure, collate, analyze and communicate insights from use of candidate varieties
	Development actor	Facilitate and organize rapid screening of candidate varieties where private and public breeders cannot
	Seed users	Participate in rapid local screening of candidate varieties
Early generation seed production		A broader variety portfolio means a more complex EGS production EGS production is a particular challenge for low-profit seed crops
	Private breeding companies	Improve 'demand inventory' system to respond to localized and changing demand
	Public breeding	Invest in developing financially sustainable EGS production models of low-profit seed
	Seed production companies	Engage in EGS production of low-profit seed
Seed multiplication		High-profit hybrid seed production can benefit from international commercial seed system and economies of scale in production Low-profit seed and VPCs requires more local production
	Seed production companies	Efficient production of high-profit seed of locally demanded varieties Local commercial production of low-profit seed
Seed marketing / dissemination		A significant additional effort in local demonstration and information provision is required to respond to more complex and localized demand
	Seed production companies	Information, demonstration and marketing of seed of low-profit seed crops
	Seed trade companies	Information, demonstration and marketing of seed of high- profit and low-profit seed crops
Seed use		Variety choice is the responsibility of the seed user, weighing agro-ecological fit, market and home consumption. Essential is to assure seed use is the experimental environment providing feedback to breeders
	Seed users	Experiment with varieties to optimize choice and associated practices
	Agricultural research	Structure, collate, analyze and communicate insights from seed users
	Agricultural advisory services	Support seed users in experimenting and making farm-specific choices on varieties, crop husbandry and marketing
	Seed production companies	Co-organize agricultural advisory services for high-profit seed crops Gain and communicate insights on variety performance and demand gained from engagement with seed users
Enabling environment	***Actors - roles***	***Observations***
Seed policy and regulation	Competitive environment void of monopoly players, level playing field Protection of breeders' rights to assure profit incentives for private sector investment Breeders' exemption to stimulate incremental innovation Easy import of candidate variety seed and commercial seed Light variety registration to promote broad variety catalogues Acceptance of crowd-sourced data of variety performance data for variety registration Seed quality assurance at retail level	
Seed sector governance	Facilitated collaboration in variety selection between public and private actors Articulation of local demand organized in both high-profit and low-profit systems	

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