

Seed value chain development in the Global South: Key issues and new directions for public breeding programs

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Jason Donovan ¹, Pieter Rutsaert ², David Spielman³, Kelvin Mashisia Shikuku⁴ and Matty Demont ⁵

Abstract

Where CGIAR breeding programs rely on the private sector for the multiplication and distribution of improved cultivars, persistent challenges have dampened their impact on varietal adoption and turnover rates. Part of the problem is that research and practice in CGIAR and among its national breeding program partners tend to treat the private sector as a vehicle for seed delivery, rather than as commercial businesses facing a range of unique constraints and threats. This paper adopts a value chain framework to examine these relationships and pathways for improved varietal adoption/turnover outcomes in three cases: hybrid maize, farmed fish, and rice. In the first two cases, weak incentives and high risks left seed companies reluctant to invest in the marketing and quality assurance efforts needed to realize near-term impacts at scale from breeding investments. In the third case, seed companies played an insignificant role: grain traders supplied certified seed to smallholders, potentially prioritizing consumers' quality preferences over climate-resilience and stress-tolerance traits for farmers. The findings raise important questions about the role of CGIAR and national breeding programs; specifically, how these programs can effectively support the private sector to deliver impact at greater scale, how consumer preferences are captured in trait prioritization within breeding programs, and what types of incentive mechanisms can be changed within breeding programs to advance a genuine shift towards 'demand-oriented' plant breeding.

Introduction

Increasing the productivity of smallholder agricultural and livestock systems in the Global South remains a development priority for many governments and donors. Smallholders in Sub-Saharan Africa and other regions have played—and are expected to continue playing—a major role in food production (Herrero et al., 2017; Ricciardi et al., 2018; Samberg et al., 2016). Population growth and urbanization will continue to put pressure on agriculture to provide nutritious foods, at affordable prices in increasing volumes (Giller, 2020). The implications of climate change, including the increased burden of biotic and abiotic stresses on crop production, add considerably to these pressures. Since the Green Revolution of the late 1960s and 1970s, the discovery, development, and delivery of improved genetic material for smallholders have remained a key element in the strategies pursued by governments and donors to increase smallholder productivity. But new challenges—new circumstances and new ways of doing business—may necessitate a change in how such strategies are designed and implemented. This is of particular concern for the international agricultural research system, including CGIAR, its largest component.¹

CGIAR, working closely with national agricultural research systems (NARS), has been successful with the

introduction of improved cultivars for smallholder production of staple food crops (Alston et al., 2000; Evenson and Gollin, 2003; Renkow and Byerlee, 2010), with reportedly high returns to investment even despite debates over the data, methods, and assumptions used to estimate such returns (Hurley et al., 2014). In pursuit of still higher returns, CGIAR and its partners have been working to become more 'demand-oriented' in design and action, particularly with respect to their breeding programs (CGIAR, 2021). This responds to long-standing criticisms that public breeding programs are out of touch with their clients (Atlin et al., 2017; Cobb et al., 2019) and to historical biases created in a technology-biased, supply-pushed

¹ International Maize and Wheat Improvement Centre (CIMMYT), Texcoco, Mexico

² International Maize and Wheat Improvement Centre (CIMMYT), Nairobi, Kenya

³ International Food Policy Research Institute (IFPRI), Kigali, Rwanda

⁴ WorldFish, Penang, Malaysia

⁵ International Rice Research Institute (IRRI), Los Baños, Philippines

Corresponding author:

International Maize and Wheat Improvement Centre (CIMMYT), Texcoco, Mexico.

Email: j.donovan@cgiar.org

approach to agriculture and rural development (Glover et al., 2019; Scoones and Thompson, 2011; Sumberg et al., 2012). Both critiques motivate and inform the growing interest in employing concepts and tools related to market segmentation strategies and product profile development to structure CGIAR breeding programs and in the prioritization of trait discovery and development (Ragot et al., 2018). Demand-oriented programs in genetic innovation and seed systems development are likely to expand within the CGIAR agenda as they pursue a new phase of operations (CGIAR, 2021).

During the last two decades, breeding programs at CGIAR centers working on cereals—including the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the International Maize and Wheat Improvement Center (CIMMYT)—have made considerable use of public-private partnerships (PPPs) and other collaboration mechanisms to engage private companies in seed production and delivery, thereby leveraging private resources, expertise, or marketing networks to scale out CGIAR-derived breeding products. When these mechanisms were first introduced, they represented a significant change from the previous public-sector driven approach where NARS carried out the design, multiplication, and distribution of improved varieties throughout much of the Global South (Tripp and Rohrbach, 2001). Private sector collaborations with public breeding programs have contributed to increases in overall investment in seed production and marketing for self-pollinated crops (e.g. wheat, sorghum and rice), vegetatively propagated crops (e.g. bananas, potatoes and casava), maize (both open-pollinated varieties and hybrids), as well as improved fish species and livestock breeds. Typically these collaborative arrangements between public and private actors are structured such that public breeding programs develop relatively finished (i.e. registered and released) materials before turning them over to private entities to handle further product testing, seed multiplication, distribution, and marketing (Spielman et al., 2010).

There is considerable interest in understanding the consequences and impacts of these collaborations in the Global South (Spielman et al., 2007; Spielman et al., 2010; Langyintuo et al., 2010; Van Mele, Bentley and Guèi, 2011). Research has highlighted both the capacity of private seed companies and the bottlenecks they face in delivering improved varieties derived from CGIAR breeding programs to smallholders. A common feature of these studies is the consideration of seed businesses as a *vehicle* for seed delivery, rather than as unique commercial operations trying to survive while facing a range of challenges and threats, including anti-competitive behavior, murky regulatory regimes, static consumer or farmer preferences, and political interference (Spielman and Smale, 2017; Tripp and Rohrbach, 2001; Rutsaert et al., 2021; Spielman and Kennedy, 2016). In this context, the future reach and ultimate impact of CGIAR breeding programs for cereals and other crops depends on recognizing the potential of the private sector and identifying options for context-appropriate approaches and new partnerships needed for seed business development.

This paper examines the implications of public-private engagement from the perspective of such businesses. It

focuses on the perspective of two specific types of private actors: farmer-facing small- and medium-sized seed production and marketing companies that engage directly with CGIAR and NARS breeding programs and grain traders/millers that contract seed production and supply to smallholders in the context of pre-existing commercial contracts. This focus on small- and medium-sized seed companies is distinct from that of larger—and often multinational—crop-science firms that manage their own large-scale breeding programs and interact with CGIAR and NARS on issues more related to R&D and intellectual property rights. The perspective is also distinct from that of smaller, more localized seed banks and seed enterprises that are managed by farmer cooperatives, women’s associations, community groups, or small-scale entrepreneurs. These actor-types are no less important to efforts to increase smallholder productivity, but arguably receive more attention in the literature than this “hidden middle” (Reardon, 2015) comprised of small and medium-scale companies operating within emerging seed value chains.

Despite the importance of this class of private actors for the ultimate success of CGIAR breeding programs, we know little about the circumstances and strategies required to build them into viable businesses able to respond to the preferences and needs of smallholders. An implied assumption that underpins the impact pathways of CGIAR breeding programs is that these actors, as compared to their multinational counterparts, are more willing to seek out traditionally underserved segments of the seed market, including small-scale, resource-poor farm households located in less-favored production zones. It remains to be seen whether this assumption is an accurate one. Another strong assumption of the impact pathway of breeding programs is that these same actors are willing and able to continuously introduce new products to market—including products derived from CGIAR and NARS breeding programs—while phasing out older varieties to stay ahead of the competition. In reality, however, evidence suggests that seed businesses tend to be reluctant to remove top selling products from the market for various reasons, including the difficulty of building market share for new varieties, a lack of investment capital or capacity to undertake the necessary marketing, or an unwillingness to challenge farmers’ loyalty to tried-and-true varieties (Spielman and Smale, 2017). This calls for critical reflection on the ideas and assumptions that underpin the design of public-private collaborations in seed production and distribution—reflections that partly require a better understanding of seed businesses themselves and what support they need.

Drawing on insights from three case studies, this paper describes the role of private sector actors (e.g. seed producing businesses, seed retailers, and grain millers and traders) in getting improved cultivars to smallholders, the incentives faced and capacities of these actors in carrying out these roles, and the contributions of public- and donor-supported breeding programs and other service providers in support of formal seed sector development. To frame the discussion across different commodities, a value chain lens is applied

on three cases: (i) maize in Kenya, (ii) fisheries in Bangladesh, and (iii) rice in Vietnam and Bangladesh. The remainder of the paper is organized as follows. Section 2 goes deeper into the value chain focus and what this means for seed sector development. Section 3 presents the three different case studies and Section 4 brings together learnings from the different cases and proposes some new directions for the CGIAR going forward with private sector engagement.

Seed from a value chain perspective

A key feature of the applied agricultural economics and agribusiness literature in recent years has been its discussion of value chains and food systems, in particular, how private companies in the Global South can better respond to consumer demand in ways that yield benefits for those involved, including processors, traders, farmers, and consumers. Researchers have turned to the value-chain analysis framework to understand design options for development interventions where the private sector can play a key role in achieving development outcomes, to include those related to poverty reduction (Gómez et al., 2011; Vos and Cattaneo, 2021), human nutrition (Tschirley et al., 2015; Reardon and Timmer, 2012), and gender equity (Devaux et al., 2018; Stoian et al., 2018). Instead of looking at a single actor or market, this analytical framework considered the range of stakeholders and their successive value-adding activities that moves a commodity from production all the way to consumption and eventual disposal (Kaplinsky and Morris, 2001). At its core, value-chain frameworks guide analysis towards (i) the preferences and needs of end-users (either farmers, downstream buyers, or consumers) and (ii) the capacities and incentives for upstream businesses (either individually or in collaboration with others) to respond to these needs with value added products and services. In this context, the potential for development programming lies in helping stakeholders to understanding clients' demands and helping upstream businesses and farmers build their strategy and capacity to respond. By better responding to clients' demand, retailers and processors should generate higher profits, with benefits for smallholders and laborers in terms of higher prices and improved working conditions. When applied to seed, a value chain lens has the potential to inform strategies to better link customers' demand (e.g. farmers, end-consumers, and agro-industry) for new varieties with the capacities, incentives and needs of upstream chain actors (e.g. seed businesses, traders/retailers, as well as input and service providers) to supply the products.

The development of value chains in the agri-food sector hinges on the willingness and capacity of independent agri-food businesses and their suppliers to invest in the higher levels of coordination, collaboration, and communication needed to respond to clients' demand. Among the most cited examples are value chains for high value, perishable products, for example fish, fruits, vegetables, and flowers, between developing regions and European and U.S. buyers. Along the same lines, however, seed can be

considered a high value product, exhibiting unique combinations of traits, requiring considerable skills and infrastructure for production and marketing, where quality can diminish rapidly with time and neglect. However, within the seed systems literature, limited attention has been given to the various actual and potential demands for improved seed, and the coordination, collaboration, and communication needed to ensure the product travels from seed companies to end-users. Research on formal seed systems development has also been mainly limited to the production of the seed in response to market liberalization (e.g. Langyintuo et al., 2010; Van Mele et al., 2011). Recent thinking on the structure of formal seed systems acknowledge the need of distribution and marketing (Louwaars and de Boef, 2012; Morris et al., 1998) but do not touch on the operational challenges.

The application of value chain thinking to a seed context presents several important challenges, to include the large variation in value chain structures and incentives between different crops and the overall difficulty of understanding consumers' demand for products such as seed with strong credence attributes. A key difference between seed and grain is that a buyer of seed can only determine the quality and utility after the seed is purchased and used in the field. To further complicate matters, the performance of the seed will depend on several factors which are unrelated to the seed itself (e.g. rainfall patterns, soil nutrients, plant diseases), but which farmers may not be able to clearly distinguish. The performance attributes inherent in new drought tolerant maize seeds, for example, will only be noticeable to farmers during years of low or sporadic rain fall. The same holds for disease resistance of new maize varieties: performance will only stand out when other varieties in the proximity of a farmer are visibly affected. The marketing and delivery of quality seed is also challenged by gaps in quality control and assurance (Barriga and Fiala, 2020; Bentley et al., 2018) as well as the persistence of counterfeit seed in some areas (Joughin, 2014).

A clear understanding of consumer demand is considered the starting point for the design of strategies for value chain development and this premise applies similarly for seed value chains. However, a growing body of literature has questioned if current priorities in trait development are in line with farmer (or other stakeholder) preferences and needs (McEwan et al., 2021; Iragaba et al., 2021; Thiele et al., 2020) and if new varieties are adequately adjusted to the heterogenous environments and farm conditions (van Etten et al., 2019; de Sousa et al., 2021). A major barrier to better understanding demand for new material is asymmetric information between seed companies and retailers and farmers, i.e. farmers exhibit limited demand for products for which they cannot assess the genetic quality aspects and attributes (Heiman and Hildebrandt, 2018), despite the potential for new products to deliver improved performance. Recent evidence from Kenya has highlighted the overall lack of information available to farmers on the attributes of seed at the point of sale (Rutsaert, Donovan and Kimenju, 2021). Economists have employed choice

experiments to understand farmers' willingness to pay for seed, but hypothetical bias is likely to strongly influence results given the strong credence attributes of seeds. While professional assessments of seed demand are available (Azoth Analytics, 2020), these tend to focus on major commercial crops of North America and Europe. Reliable data on seed sales and uptake by cultivar type in developing regions remain very scarce.

The ultimate impact of breeding programs depends on farmers seeking out new cultivars when they are informed about the superiority of the new material. Yet, various factors shape farmer seed choices and purchase decisions to include those related to socio-demographics (e.g. age, gender, education, experience), commodity use (e.g. sales, own consumption) and commodity utilization (e.g. processing, type of dish). Moreover, exogenous factors shape farmer seed choices such as seed availability, seed quality and price as well as information on available options and past experiences. While traits associated with production constraints and conditions in targeted agro-ecologies remain essential for varietal performance, there is a growing awareness of the need to encompass consumer-preferred traits along the value chain into breeding. The inclusion of more consumer-preferred traits could help further increase the adoption of new varieties and speed up varietal replacement (Custodio et al., 2016; Thiele et al., 2020).

Value chain researchers have also called attention to how the overall regulatory and policy environment shapes the opportunities for businesses along the chain. Throughout much of the Global South, seed value chains continue to be closely managed by governments. Strict policies, regulations, and procedures often shape a range of business activities (Spielman and Kennedy, 2016); Spielman and Smale, 2017). This includes, for example, rules on who is permitted to invest in seed production and distribution; how early generation seed is accessed from public breeding programs; how seed quality is evaluated and monitored; and even what prices seed businesses can charge their end-users. While such policy environments are often designed to protect farmers from predatory behavior, they may also pose significant barriers to entry that may favor incumbent state-owned seed enterprises or large multinational firms with the resources and expertise required to navigate the ins and outs of policy. Understanding the role of policy in either encouraging or constraining seed business growth is critical to understanding how CGIAR and NARS breeding programs will succeed not only in leveraging the private sector to produce, distribute, and market new cultivars, but also in shaping breeding programs' understanding of the demand for specific traits.

Case-studies

In this section we present three diverse case studies that describe opportunities for seed value chain development: maize in Kenya, fisheries in Bangladesh, and rice in Vietnam and Bangladesh. The cases focus on the strategies and capacities of seed companies and retailers, as well as

grain traders and millers, to get quality new material into the hands of farmers and the role of public breeding programs in the process. An assessment of the ultimate impact of these value chains on smallholder production and livelihoods falls outside the scope of the cases: however, getting quality seed produced and delivered is a fundamental requirement for seed value chains to achieve such impact, for which more attention is merited.

Maize in Kenya

One important example of engagement between public breeding programs and private seed companies is found in the case of hybrid maize in Kenya and elsewhere in Eastern Africa. Private seed companies—generally small in scale and focused on hybrid maize production and distribution—collaborate closely with donor and public sector breeding programs to secure parent lines and multiply seed of F1 hybrids, often, though not always, on a non-exclusive basis (Prasanna et al., 2021; Worku et al., 2020). These same companies leverage support from donors, seed sector associations, and national agricultural research systems in terms of funding, technical backstopping, and quality assurance (AGRA, 2017; Access to Seeds Foundation, 2019). They operate alongside—and sometimes in collaboration with—regional and multinational seed companies that produce and distribute their own proprietary hybrids. Taken together, these investments have contributed to a doubling of local seed production volumes over the last decade in Eastern Africa (Rutsaert et al., 2021), and the rapid proliferation of improved maize varieties across the same region (Abate et al., 2017). However, adoption of new and more stress-resilient maize varieties is still lagging (Walker and Alwang, 2015; Spielman and Smale, 2017; Rutsaert and Donovan, 2020). By all accounts, significant challenges remain to introduce a continuous flow of new varieties and accelerating varietal turnover in these markets. A key, yet rarely discussed, limitation of the supply-oriented strategy appears to be the lower-than-expected capacity and willingness of the private sector to continuously invest in the production, testing and marketing of new germplasm. As a result, farmers do not gain access to genetic improvements on the same cycle—every four years or so—that their counterparts in industrialized countries enjoy and expect (Atlin et al., 2017; Spielman and Smale, 2017). This warrants a closer look at how the seed value chain is organized in Kenya, the capacities of different actors to drive the innovation and identification of areas for stronger sector support.

The model for hybrid maize seed production and distribution in Kenya rests primarily on the business strategies and decisions of dozens of small-scale, privately owned seed companies that multiply and distribute seed to thousands of independent agro-dealers (alongside government input distribution programs) that bundle improved varieties with fertilizer and other inputs for smallholders. This is an important distinction with the Global North where seed companies have sought to build direct, long-term relationships with large-scale farmers who purchase large

volumes of seed (Fitzgerald, 1993). Yet seed companies in Kenya tend to mimic this business model with marketing approaches that seek to “pull” demand from farmers: demonstration plots that provide side-by-side comparisons of competitive varieties; support to ‘lead farmers’, e.g. provision of seed and services at no cost in exchange for promotional efforts; and hiring of locally embedded sales agents to build demand and brand recognition. In highly fragmented smallholder production systems, however, this is a costly approach, and tends to divert seed companies away from other investments such as launching and marketing new hybrids. Necessarily, there are significant risks to companies that update their product offerings and portfolio. Recent work by Rutsaert et al. (2021) demonstrates that these factors may contribute to risk-averse innovation strategies among private seed companies in Kenya instead of the persistent drive to update their germplasm which donors and public breeding programs have come to expect. Indeed, when seed companies have invested in promoting existing varieties and secured significant market shares, they may be reluctant to remove these successful products from the market while simultaneously bearing the risks of a new, and potentially unsuccessful, product launch in a highly competitive environment (Spielman et al., 2010). Many seed companies also tend to operate on an uneven playing field where state-owned enterprises, well-connected businesses with preferential access to government contracts, seed subsidy programs, and emergency seed relief efforts tend to disrupt the market.

The key to changing these dynamics and accelerating genetic gain in farmers’ fields is to (1) improve our understanding of how seed retail networks function and how farmers make seed choices, and (2) promote interventions that shape the trajectories of retail network growth and farmer decision-making. Our analysis indicates that the root cause of the problem is that while independent agro-dealers form the last step in the distribution pathway, seed companies tend to bypass them—and the retail networks that form around them—to assume responsibility for the marketing and promotion of their hybrids (Rutsaert and Donovan, 2020). As a result, seed companies invest heavily in maintaining direct influence over their products and customers, rather than innovating through potentially lower-cost and higher-reach networks that are closer to their customers and possibly better positioned to realize efficiencies of scale and scope in seed distribution.

While variation exists between countries in terms of the quality and reach of agro-dealer networks, multiple donors, non-governmental organizations, business incubators, and social enterprises have supported the growth and professionalization of these networks (Adesina et al., 2014; Makinde and Muhhuku, 2017; Odame and Muange, 2011). However, little is known about their active role in informing and guiding farmer practices, despite high expectations (Allgood, 2011). A recent study in Uganda looking at pesticide sales found that technical knowledge, understanding of labels and proper handling of pesticides by agro-dealers was often inadequate (Staudacher et al.,

2021). Another study in Kenya suggested that maize seed-stocking decisions by agro-dealers were mainly guided by farmer demand, with little interest in, or active promotion of, new hybrids (Rutsaert et al., 2021). Liquidity constraints, combined with low margins from seed sales and strong competition among retailers, implied that few agro-dealers were able or willing to invest in in-store marketing.

Indeed, agro-dealers’ lack of interest in marketing is reflected in farmers’ own decision-making. Maize farmers in Kenya showed weak appetite for purchasing new varieties, preferring instead to purchase varieties with which they had direct experience (Rutsaert et al., 2021). Additionally, farmers were reluctant to question their own seed choice or pay attention to different options in store (Rutsaert et al., 2021), highlighting the very intuitive nature of the seed purchasing decision. This suggests that rather than a mismatch between farmer trait preferences and breeding priorities, it is the much more complex dynamics of seed purchasing behavior that shapes varietal turnover.

Public policy also plays a role in shaping agro-dealer networks and farmers’ seed purchasing decisions. In many countries, small-scale seed companies are essentially providing the same offerings in different packaging because they have limited access to the early generation seed from public breeding programs that is necessary to develop new and competitive hybrids. In other cases—and as noted before—market distortions created by state-owned enterprises, well-connected businesses with preferential access to government contracts, seed subsidy programs, and emergency seed relief efforts tend to coalesce around the distribution of known varieties at below-market prices. The absence of anti-trust action by regulators and judicial systems combined with persistent rent-seeking behavior and political economy factors tends to maintain the status quo, leading to less-than-competitive seed markets and insufficient product innovation, which also contributes to limited genetic gains in farmers’ fields.

As these complex issues come to light, the academic discourse around hybrid maize in Eastern Africa is shifting from an adoption challenge (getting farmers to pay for hybrid seed instead of recycling seed) to a marketing challenge (influencing the ways in which farmers obtain information and make choices). This opens the door to new work in value-chain analysis and experimentation with new forms of inter-business relations, innovations in marketing, and market information management systems, recognizing that high levels of marketing capacity are essential to accelerate farmer uptake of new varieties (Heiman and Hildebrandt, 2018). Yet, regional and local discussions on these topics remain infrequent, despite a growing recognition that private sector partners on their own are potentially ill-equipped to drive the change that the development community seeks.

Fisheries in Bangladesh

Our second seed value chain case looks at genetically improved farmed tilapia (GIFT) in Bangladesh. Private hatcheries constitute farmers’ main source of GIFT fry in

the country. In the nomenclature of fish seed, the larvae emerging from the fertilized eggs after hatching is called hatchling. As soon as the yolk sac of the hatchling is absorbed it is known as spawn and as soon as the spawn assume the shape of the fish and grow to about 1–2 cm it is known as fry. When a fry reaches 10–15 cm size it is known as a fingerling. The private hatcheries are of two categories (Figure 1). The first category comprises broodstock multiplication hatcheries that collaborate with WorldFish (CGIAR) and the public sector breeding program at the Bangladesh Fisheries Research Institute (BFRI) to maintain parent lines and produce quality broodstock. Broodstock are a group of mature individual fish used in aquaculture for breeding purposes. The second category comprises private multiplication hatcheries that manage production of quality fry and fingerlings from the broodstock. Together, the introduction of GIFT strain, establishment of hatcheries in private sector, technological innovation in the production of mono-sex (all male) fry, and adoption of best management practices are largely seen as the major contributing factors to the 18-fold increase in tilapia production in Bangladesh between 2005 and 2015 (FAO, 2018).² Despite the remarkable growth in the number of GIFT hatcheries and the substantial increase in the supply of quality fry and fingerlings, there remains challenges related to low quality broodstock and use of poor management practices which generate disappointing outcomes in eggs and fry production (Shikuku et al., 2021). This in turn causes

low demand for fry by farmers and diminishes hatcheries' interest in fry production business.

There are two main models of GIFT seed dissemination in Bangladesh. The first model starts with the government-operated BFRI as the producer of GIFT mixed sex fry for selling to privately owned hatcheries that grow the fry to broodstock and produce GIFT mono-sex fry for selling to farmers (Kohinoor et al., 2016). The second model was established in 2011 with support of WorldFish. The model starts with CGIAR developing improved germplasm which is then disseminated to a select few privately owned broodstock multiplication hatcheries, selected based on their infrastructure base and technical capacity to produce high quality broodstock using rotational cohort mating scheme to minimize inbreeding. The rotational cohort mating scheme involves dividing the selected population into groups (cohorts). In each generation, males from one cohort are systematically mated with females from another cohort (Lind et al., 2012). The rotational pattern changes in each generation. Broodstock multiplication hatcheries in the second model produce broodstock for their own commercial seed production units or sell mixed-sex fry to private sector hatcheries that grow the fry to broodstock and produce GIFT mono-sex fry for selling to farmers (Shikuku et al., 2021). Broodstock multiplication hatcheries in this second model also sell mono-sex fry directly to farmers.

Eighty percent of the mono-sex GIFT fry is distributed by hatcheries directly to farmers and 20% indirectly through fingerling traders (Shikuku et al., 2021). Dey et al. (2005) reported that traders represented 35% of the

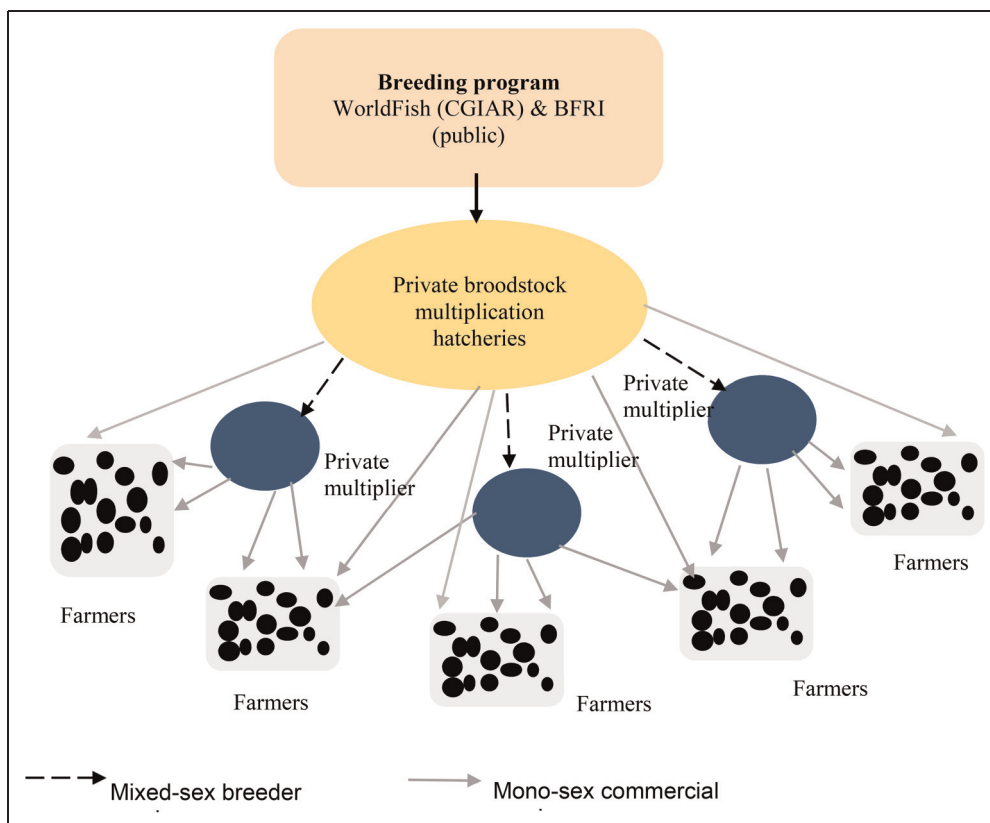


Figure 1. Actors in the value chain for the genetically improved farmed tilapia (GIFT).

source of fingerlings for farmers in Bangladesh. Overall, demand for GIFT commercial seed can be high. For example, a recent survey of privately owned GIFT hatcheries found that most experienced a situation where fingerling supply could not meet the known demand (Shikuku et al., 2021). However, there are some important challenges in GIFT value chains, which taken together, reduce the return on breeding efforts by WorldFish and BFRI. As earlier mentioned, a critical and persistent problem in the dissemination of GIFT fingerlings is the poor quality of broodstock and high degree of inbreeding. Recommended good practice requires that multiplication hatcheries renew their broodstock at least every two years. However, most multiplication hatcheries rely on their own seed to produce broodstock. Furthermore, failure by multiplication hatcheries to replace their broodstock using quality GIFT broodstock from breeding hatcheries has implications on the business model for the latter. Specifically, this tendency introduces a source of demand risk for the breeding hatcheries forcing them to modify their business model and compete with the multiplication hatcheries in the production of GIFT mono-sex seed. Limited market access and high transportation cost affect distribution of GIFT fry and fingerlings by privately owned GIFT hatcheries. Perceived lower market prices for fry and fingerlings relative to the high production cost is a disincentive to the dissemination of quality fry and fingerlings. Evidence from multistakeholder workshops showed that private sector hatcheries in Bangladesh perceived unfair competition from unregistered hatcheries and brokers as a barrier to successful market penetration (Shikuku et al., 2021). Complete enforcement, by the public sector, of regulatory frameworks, particularly the Fisheries Hatchery Act 2010 and Rule 2011 (Shamsuzzaman et al., 2016) and establishment of a certification scheme for hatchery and fish seed quality are perceived as promising solutions to these problems. Most GIFT hatcheries have a wide clientele coverage. For example, hatcheries located in the north have clients in the south and vice versa (Rashid and Zhang, 2019). However, poor roads infrastructure increase transportation and transaction costs associated with delivery of fry and fingerlings to clients. Delayed delivery of fry and fingerlings because of poor roads network reduces survival and growth rates for fish consequently depressing yield and profitability and reducing effective demand for quality fry and fingerlings by farmers.

There have been efforts to assess on-farm performance of GIFT. These efforts document that GIFT grows 27–36% faster than non-GIFT strains in Bangladesh (Tran et al., 2021). However, empirical evidence on consumer preferences and the factors influencing farmers' demand for GIFT seed is scant. The lack of insights on consumer preferences may explain why fish breeding programmes by WorldFish and NARS have not included user preferences in their product profile design (Mehtar et al., 2020). Efforts to understand end-user preferences will need to address the heterogeneity in preferences for fish traits along the value chain. For example, hatcheries might be more interested in growth, survival, and resilience (Mehtar

et al., 2020) while the mode of transportation and distance travelled influence seed traders' demand for traits associated with survivability of fingerlings (Islam and Hossain, 2013). Studies have also assessed preferences for traits by different categories of farmers and across diverse environments (e.g. Sae-Lim et al., 2016; Omasaki et al., 2016). However, less attention has been given to gender-disaggregated preferences (Mehtar et al., 2020).

Rice in Vietnam and Bangladesh

Our third value chain case describes the potential for private sector leadership in varietal rice seed production and distribution in Vietnam and Bangladesh, driven by growing end-consumers' demands for higher quality rice grains and the response of the grain sector to meet those needs. As discussed by Tripp and Pal (2001), cases of private sector involvement in seed production of self-pollinating varieties such as rice, wheat, and grain legumes, and open-pollinated varieties as maize, pearl millet and sorghum, developed by the public sector, are few due to low sustained demand (as farmers can easily save seed once a new variety was acquired) and lower commercial value compared to hybrids. Like other non-hybrid crops, new varieties tend to be delivered to farmers through government seed provision and extension. Reduced government investments in agriculture and shifting priorities in the 1980s weakened the scaling mechanism, with major negative consequences for varietal turnover and impact of public and donor supported breeding programs (Atlin et al., 2017).

During the green revolution in the 1970s, the Vietnamese government has made large investments to transform rice production in the Mekong Delta by investing in irrigation, promotion of improved varieties and fertilizer and switching to double and triple cropping systems. Through large public investments in the rice sector, combined with relatively low production costs, the country transformed itself from a net importer of rice to a net exporter of low-medium quality rice (Demont and Rutsaert, 2017). However, in the last decade it became clear that rising costs for fertilizer, fuel, and labor had reduced the country's competitiveness in the export of low-medium quality rice. On top of that, the intensive use of fertilizer and pesticides in the Mekong Delta has also led to detrimental effects on water quality, biodiversity, and human health (Flor et al., 2021). At the same time, consumers in South and Southeast Asia have become more demanding in terms of grain quality attributes of rice, such as fragrance and uniform grain texture (Custodio et al., 2016; Mottaleb and Mishra, 2016). To tap into higher quality grain markets as well as shift towards more sustainable production practices, a large-scale program of Sustainable Agricultural Transformation (VnSAT) was implemented with the support of the World Bank (The World Bank, 2016).

Strategies for the development of the export-oriented rice value chain began to refocus on reaching higher quality market segments, implying higher levels of uniformity in grain, reduced pesticide use and focus on fragrant

rice. To support product upgrading, the government introduced policies to encourage (i) stronger vertical coordination between exporters and farmers through contract farming, and (ii) horizontal coordination among farmers through the “small farm, large field” (SFLF) program (Ba et al., 2019). Under the SFLF program, the government supports farmers in pooling their land, adopting uniform varieties and production practices, and synchronizing their planting and harvesting dates. Farmer groups under the SFLF program were also encouraged to shift towards sustainable farming practices (Stuart et al., 2018). Besides reducing inputs such as pesticides, fertilizer and water, a key requirement for rice farmers was the use of certified seeds. Like the case of other non-hybrid cereals, Vietnamese farmers obtained rice seed via informal seed systems (Tin et al., 2011), and, when feasible, tended to rely on seed that was saved from the previous grain harvest. However, under the SFLF program, registered farmer groups produce the certified seed, with the Ministry of Agriculture and Rural Development (MARD) providing technical support and Department of Agriculture and Rural Development (DARD) providing foundation seed and certification services (Flor et al., 2021).

In practice, it was the grain export companies that took the lead in the shift from farmer saved seed to certified seeds. They provided certified seed, sourced from registered farmer groups that specialize in seed production, to their contract farmers, together with chemicals and in some cases credit. This contractual arrangement helped rice farmers access quality seed and other inputs, while also helping exporters to control for product quality and reach higher-value markets. By introducing an enabling environment for rice production and export, the government encouraged private sector investment in a formal seed sector with coordination from seed to end-product. Other rice sectors (e.g. Cambodia, Thailand, India and even some countries in Africa) are currently following similar pathways, triggered by competitive forces and demand for quality in end-markets (e.g. Soullier et al., 2020).

The demand focus puts new actors such as export companies as enablers for increased seed demand and production, but also gives them the key to determine varietal selection of farmers. While the attention for end-user traits such as fragrance or slenderness are obvious in prioritization of varieties, it remains to be seen how much attention will be given to production-oriented traits such as stress tolerance. On top of the damaging effects of intensive production, sea-level rise and salinity stress driven by climate change has become a major threat for rice production in the Mekong Delta (Nguyen and Woodroffe, 2016). Public sector breeding programs are focusing on abiotic stresses and salt tolerance of new varieties (Tin et al., 2021b) that are suitable for the Mekong Delta and are actively including farmer feedback through participatory varietal selection (Tin et al., 2021a). However, with decision making power beyond the farmer, these breeding programs could increase their chances on impact by collaborating with a broader range of stakeholders.

An interesting case of this is ACI (Advanced Chemical Industries) in Bangladesh that started as chemical

company supplying crop protection solutions and fertilizers to farmers. Triggered by increasing demand for sustainable agro-chemical solutions, the company started progressively integrating downstream by buying grain from farmers, incorporating seed business, then mechanization, milling, branding and retailing of rice. The company then started coordinating vertically with farmers by providing seed and contracting rice growing to govern quality of their premium rice brands. In a final step towards full vertical integration, ACI integrated rice breeding into their business model, supported by USAID funds and support from the International Rice Research Institute (IRRI) (<https://www.irri.org/news-and-events/news/irri-and-aci-partner-develop-improved-rice-varieties-rice-growers-bangladesh>). This latter step gives them full control over the quality of their rice brands, i.e. from breeding to retail. This example illustrates how competitive forces in the market—in this case the need to govern quality and sustainability of products—can attract private sector investment in seed systems and even plant breeding.

Key issues and new directions

These three cases explored the structures and incentives along seed value chains and the implications for how improved cultivars are designed, produced, and marketed to smallholders. An important proposition in the value chain framework is that intensive coordination and communication are required to deliver higher-value products to consumers. Where the private sector had clear incentives for investment in seed production and delivery, this can happen, as illustrated in the rice case. However, this was also the case where seed production and distribution were relatively low-risk activities and where farmers had a clear incentive to experiment with the new varieties because they provided access to higher-value export markets. However, in the two other cases, maize and GIFT, relatively complex value-chain structures (e.g. large number of small-scale businesses at multiple nodes of the chain), combined with more complex production processes, and information asymmetries facing farmers regarding seed options or quality, resulted in low levels of coordination and communication, with significant consequences for all actors involved. However, for maize seed businesses and retailers, arms’ length coordination and communication may not be a problem per se—rather, the approach offers a relatively low-cost, low-risk way of quickly getting seed out to farmers. The turnover problem, therefore, exists for governments and development agencies looking to advance goals related to poverty reduction and food security, among others, by getting the ‘right’ seed to farmers. The willingness of producers and retailers to increase investments is likely to remain low without changes in the overall context in which the value chain operates.

The rice sector cases raise important questions about how CGIAR breeding programs design their products and engage with actors in seed value chains. Traditionally, CGIAR designs an improved cultivar based on agronomic

factors and conditions, and then engages with government agencies (public research organizations and extension services) in target countries for seed registration, multiplication, and delivery. The number of released varieties remains a key indicator of success for CGIAR and public sector breeding programs. Therefore, the findings from the rice case suggests that private actors are willing to engage in non-hybrid production when there is a clear objective—in this case, to improve the quality of rice for sale in higher-value rice markets. Indeed, the argument for closer engagement by breeding programs with seed value chains has been made earlier by, e.g., Tripp et al. (2010), who admonished public breeders for expecting new releases to automatically move into public delivery and encouraged them to work more closely with private seed enterprises to accelerate delivery. These cases extend this point, suggesting the need for CGIAR and its partners to look not only to private seed enterprises, but also to other actors in the value chain who are incentivized and have the capacity to move new products into farmers' fields.

The findings for the maize and GIFT cases suggest that CGIAR and its donors need to focus more attention on seed value chain development. The capacity of the seed value chain to get more improved cultivars to smallholders hinged primarily on the strategies, capacities, and incentives of a single group of businesses: seed-producing businesses in maize and multiplication broodfish hatcheries in GIFT. In particular, the maize case highlighted the tendency of seed businesses to maintain an arm's distance from retailers and reduce their risks by focusing production on the older varieties with proven demand, while the GIFT case highlighted how basic conditions for the growth of seed value chains, to include quality assurance and control, have yet to be met. The capacity of seed businesses to drive increased sales and turnover of improved cultivars implies not only that they respond to farmer demand, but also requires engagement with retailers and farmers in nudging farmers' seed related decisions (e.g. annual purchase of hybrids, preferences towards new varieties). This will require innovation in how local seed businesses market seed, and donor support can help to identify potential costs and benefits of seed marketing tools. Besides direct support to companies, the potential role of the public sector in supporting social marketing, building on the approaches and associated learnings from the public health literature, to promote the benefits of planting new cultivars needs attention. Overall, the evidence base to inform government agencies, NGOs and others on how to design, implement and monitor their support for seed businesses to scale out new technologies remains surprisingly weak, especially in contrast to the large, long-term investments in the development of new cultivars. Previous reflections on the design of approaches for value chain development in the agricultural sector highlighted the need for context-relevant guidance to facilitate engagement with practitioners (Donovan et al., 2015).

It cannot be expected that the private sector alone will be the driver of innovation that leads to varietal turnover (e.g. hybrid maize in Kenya) or integration of stress-resilience (e.g. salinity tolerance in rice). Tripp and Pal (2001)

described this in their discussion of private sector involvement in rice production in the Indian state of Andhra Pradesh. While private seed companies were actively engaged in production of a non-hybrid crop, they were not driving adoption and, in fact, invested little in seed promotion. The increasing competition in seed markets warrants the need to develop new mechanisms under which private sector partners can spearhead innovations without taking a leap of faith. One option could be to link seed companies to third party service providers that provide expertise and support in market intelligence, sales, and business management among others, along the lines of early generation seed support (USAID, 2016). Policy interventions such as targeted subsidy programs linked to new seed varieties could also provide a safety cushion (de-risking mechanisms) for seed companies and help with establishing market share (Spielman and Smale, 2017). A more extreme scenario is the forced retirement or deregistration of older varieties to make space for new materials embodying new traits. However, this could have serious negative implications for (i) the numerous small-scale seed companies with limited financial reserves and marketing capacity that compete directly with multinationals and parastatal seed companies, as well as for (ii) farmers who lose access to their preferred seed and who are ill informed about alternative options, some of whom may return to saving seed.

Another set of policy interventions relate to the regulatory side of seed markets. Small-scale seed companies are often unable to compete due to regulations that require significant expenditures on meeting outdated quality control requirements, such as field-to-bag seed inspection regimes that may have little bearing on the ultimate quality of seed sold to farmers. Instead, policymakers and regulators may consider moving slowly but steadily towards professionalization of seed sector actors, internal quality assurance systems, and truthful labeling as a means of lowering barriers to entry for small-scale seed companies and encouraging seed sector growth. These findings raise important questions about the role of CGIAR and national breeding programs in relation to the private sector. Looking to the future there are significant opportunities for CGIAR and national breeding programs to shift their operational model to one that deepens and broadens collaboration with the private sector to deliver impact at greater scale. This means understanding how seed companies—especially that class of domestic, small-scale companies that have relatively limited resources and capacity in marketing and outreach—operate, and how they can be further supported and strengthened. It also means understanding that trait prioritizations that reflect consumer preferences may not be conveyed by seed companies at all, and that collaborations with other value chain actors will also be important in the design of breeding programs and prioritization of traits.

What remains to be seen is whether different types of incentive mechanisms can be introduced within breeding programs to advance a genuine shift towards 'demand-oriented' plant breeding. The current changes being

introduced into CGIAR strongly suggest that this shift is already underway, although the extent to which it affects operational modalities in national breeding programs is unknown. Irrespective of changes in CGIAR and their immediate national partners, private sector engagement in formal seed systems is likely to expand and diversify in response to opportunities in end-consumer markets, changes in the policy and regulatory environment, and engagement with governments and donors. New actors are shaping the seed value chain in ways that many breeding programs have yet to fully understand, especially those programs wedded to outdated impact pathways. Only by paying greater attention to demand orientation, market intelligence, product profiling, and seed systems development will CGIAR and national breeding programs be able to deliver the productivity and welfare gains they have promised.

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ORCID iDs

Jason Donovan  <https://orcid.org/0000-0001-7733-7451>
Pieter Rutsaert  <https://orcid.org/0000-0001-9691-6088>
Matty Demont  <https://orcid.org/0000-0001-9086-5654>

Notes

1. Established in 1971 as the Consultative Group on International Agricultural Research, CGIAR is a global research partnership for a food secure future dedicated to reducing poverty, enhancing food and nutrition security, and improving natural resources. See <https://www.cgiar.org/> for additional details on its mandate, mission, and history.
2. Tilapia fish are very prolific species and this prevents optimum growth of the fish or low conversion of feed to flesh (Fregene et al., 2021). In the female fish especially, metabolic energy is directed toward reproduction. Therefore, male tilapia fish are economically attractive because they have faster growth rate in which metabolic energy is channelled towards growth. It is, therefore, advisable to adopt mono-sex culture (Ponzoni

et al., 2005; Nguyen et al., 2007). Mono-sex tilapia (all-male production) can be obtained by manual sexing, use of hormones, genetically improved farmed tilapia, YY male technology, or hybrids (Fregene, et al., 2021).

References

- Abate T, Fisher M, Abdoulaye T, et al. (2017) Characteristics of maize cultivars in Africa: How modern are they and how many do smallholder farmers grow? *Agriculture & Food Security* 6: 30.
- Access to Seeds Foundation (2019) Access to Seeds Index 2019 Synthesis Report: Bridging the gap between the world's leading seed companies and the smallholder farmer. Amsterdam: Access to Seeds Foundation.
- Adesina A, Langyintuo A, Bugo N, et al. (2014) Improving farmers' access to agricultural inputs and finance: Approaches and lessons from sub-Saharan Africa. In: Hazell P and Rahman A (eds) *New Directions for Smallholder Agriculture*. Oxford Scholarship Online, 250–323.
- AGRA (2017) *Seeding an African Green Revolution: The PASS Journey*. Nairobi, Kenya: Alliance for a Green Revolution in Africa (AGRA).
- Allgood J (2011) Agrodealer development in developing and emerging Markets. In: AIARD Annual Conference 2011, pp.231–235. Washington, DC: International Fertilizer Development Center (IFDC).
- Alston JM, Chan-Kang C, Marra MC, et al. (2000) A meta-analysis of rates of return to agricultural R&D: Ex pede herculem. In: *Research Report*, pp. 113. Washington DC: International Food Policy Research Institute., Vol. 113
- Analytics A (2020) Global seed market-analysis by seed type, traits, by crop type, by region, by country: Market insight, competition and forecast 2019-2024. Azoth Analytics, Ghaziabad, India.
- Atlin GN, Cairns JE and Das B (2017) Rapid breeding and varietal replacement are critical to adaptation of cropping systems in the developing world to climate change. *Global Food Security* 12: 31–37.
- Ba HA, de Mey Y, Thoron S, et al. (2019) Inclusiveness of contract farming along the vertical coordination continuum: Evidence from the Vietnamese rice sector. *Land Use Policy* 87: 104050.
- Barriga A and Fiala N (2020) The supply chain for seed in Uganda: Where does it go wrong? *World Development* 130: 104928.
- Bentley JW, Andrade-Piedra J, Demo P, et al. (2018) Understanding root, tuber, and banana seed systems and coordination breakdown: A multi-stakeholder framework. *Journal of Crop Improvement* 32: 599–621.
- CGIAR (2021) *CGIAR 2030 Research and innovation strategy: Transforming food, Land, and Water Systems in a Climate Crisis*. Montpellier: CGIAR, 36 pages.
- Cobb JN, Juma RU, Biswas PS, et al. (2019) Enhancing the rate of genetic gain in public-sector plant breeding programs: Lessons from the breeder's equation. *Theoretical and Applied Genetics* 132: 627–645.
- Custodio MC, Demont M, Laborte A, et al. (2016) Improving food security in Asia through consumer-focused rice breeding. *Global Food Security* 9: 19–28.
- Demont M and Rutsaert P (2017) Restructuring the Vietnamese rice sector: Towards increasing sustainability. *Sustainability* 9: 325.

- de Sousa K, van Etten J, Poland J, et al. (2021) Data-driven decentralized breeding increases prediction accuracy in a challenging crop production environment. *Communications Biology* 4: 944.
- Devaux A, Torero M, Donovan J, et al. (2018) Agricultural innovation and inclusive value-chain development: A review. *Journal of Agribusiness in Developing and Emerging Economies* 8: 99–123.
- Dey MM, Briones RM and Ahmed M (2005) Disaggregated analysis of fish supply, demand, and trade in Asia: Baseline model and estimation strategy. *Aquaculture Economics & Management* 9: 113–139.
- Donovan J, Franzel S, Cunha M, et al. (2015) Guides for value chain development: A comparative review. *Journal of Agribusiness in Development and Emerging Economies* 5: 2–23.
- Evenson RE and Gollin D (2003) Assessing the impact of the Green revolution, 1960 to 2000. *Science* 300: 758–762.
- Fitzgerald D (1993) Farmers deskilled: Hybrid corn and farmers' work. *Technology and Culture* 34: 324–343.
- Flor RJ, Tuan LA, Hung NV, et al. (2021) Unpacking the processes that catalyzed the adoption of best management practices for lowland irrigated rice in the Mekong Delta. *Agronomy* 11: 1707.
- Food and Agriculture Organization of the United Nations (FAO) (2018) The state of world fisheries and aquaculture: meeting the sustainable development goals, Rome, Italy.
- Fregene BT, Karisa HC, Olaniyi AA, et al. (2021) Extension manual on mono-sex tilapia production and management In: *Technologies for African Agricultural Transformation (TAAT) Aquaculture Compact* (First Edition). Penang, Malaysia: WorldFish.
- Giller K (2020) The food security conundrum of sub-Saharan Africa. *Global Food Security* 26: 100431.
- Glover D, Sumberg J, Ton G, et al. (2019) Rethinking technological change in smallholder agriculture. *Outlook on Agriculture* 48: 169–180.
- Gómez MI, Barrett CB, Buck LE, et al. (2011) Research principles for developing country food value chains. *Science (new York, N Y)* 332: 1154–1155.
- Heiman A and Hildebrandt L (2018) Marketing as a risk management mechanism with applications in agriculture, resources, and food management. *Annual Review of Resource Economics* 10: 253–277.
- Herrero M, Thornton PK, Power B, et al. (2017) Farming and the geography of nutrient production for human use: A transdisciplinary analysis. *The Lancet Planetary Health* 1: e33–e42.
- Hurley TM, Rao X and Pardey PG (2014) Re-examining the reported rates of return to food and agricultural research and development. *American Journal of Agricultural Economics* 96: 1492–1504.
- Iragaba P, Hamba S, Nuwamanya E, et al. (2021) Identification of cassava quality attributes preferred by Ugandan users along the food chain. *International Journal of Food Science & Technology* 56: 1184–1192.
- Islam MN and Hossain MA (2013) Mortality rate of fish seeds (labeo rohita) during traditional transportation system in the northwest Bangladesh. *Journal of Scientific Research* 5: 383–392.
- Joughin J. (2014) The political economy of seed reform in Uganda: Promoting a regional seed trade market In: *Africa Trade Practice Working Paper Series Nr 3*. Washington, D.C.: World Bank Group, 48 pages.
- Kaplinsky R and Morris M (2001) *A Handbook for Value Chain Research*. Ottawa, Canada: International Development Research Centre (IDRC).
- Kohinoor AHM, Rahman MA, Islam S, et al. (2016) Upgradation of genetically improved farmed tilapia (GIFT) strain by family selection in Bangladesh. *International Journal of Fisheries and Aquatic Studies* 4: 650–654.
- Langyintuo AS, Mwangi W, Diallo AO, et al. (2010) Challenges of the maize seed industry in Eastern and Southern Africa: A compelling case for private–public intervention to promote growth. *Food Policy* 35: 323–331.
- Lind C, Ponzoni R, Nguyen N, et al. (2012) Selective breeding in fish and conservation of genetic resources for aquaculture. *Reproduction in Domestic Animals* 47: 255–263.
- Louwaars NP and de Boef WS (2012) Integrated seed sector development in Africa: A conceptual framework for creating coherence between practices, programs, and policies. *Journal of Crop Improvement* 26: 39–59.
- Makinde K and Muhhuku F. (2017) Getting improved seeds to smallholder farmers through agro-dealer networks In: *Seeding an African Green Revolution: The PASS Journey* pp. 89–107: Nairobi, Kenya: AGRA, .
- McEwan MA, Almekinders CJ, Andrade-Piedra JJ, et al. (2021) “Breaking through the 40% adoption ceiling: Mind the seed system gaps.” A perspective on seed systems research for development in One CGIAR. *Outlook on Agriculture* 0: 0030727021989346.
- Mehar M, Mekki W, McDougall C, et al. (2020) Fish trait preferences: A review of existing knowledge and implications for breeding programmes. *Reviews in Aquaculture* 12: 1273–1296.
- Morris M, Rusike J and Smale M (1998) Maize seed industries: A conceptual framework. In: Morris M (eds) *Maize Seed Industries in Developing Countries*. Boulder, Colorado: Rynne Rienner, 35–53.
- Mottaleb KA and Mishra AK (2016) Rice consumption and grain-type preference by household: A Bangladesh case. *Journal of Agricultural and Applied Economics* 48: 298–319.
- Nguyen NH, Khaw HL, Ponzoni RW, et al. (2007) Can sexual dimorphism and body shape be altered in Nile tilapia (*Oreochromis niloticus*) by genetic means? *Aquaculture* 272S1: S38–S46.
- Nguyen NH and Woodroffe CD (2016) Assessing relative vulnerability to sea-level rise in the western part of the Mekong river Delta in Vietnam. *Sustainability Science* 11: 645–659.
- Odame H and Muange E (2011) Can agro-dealers deliver the Green revolution in Kenya? *IDS Bulletin* 42: 78–89.
- Omasaki SK, van Arendonk JA, Kahi AK, et al. (2016) Defining a breeding objective for Nile tilapia that takes into account the diversity of smallholder production systems. *Journal of Animal Breeding and Genetics* 133: 404–413.
- Ponzoni RW, Hamzah A, Tan S, et al. (2005) Genetic parameters and response to selection for live weight in the GIFT strain of Nile tilapia (*Oreochromis niloticus*). *Aquaculture* 247: 203–210.
- Prasanna BM, Cairns JE, Zaidi PH, et al. (2021) Beat the stress: Breeding for climate resilience in maize for the tropical rainfed environments. *Theoretical and Applied Genetics* 134: 1729–1752.
- Ragot M, Bonierbale M and Weltzien E (2018) *From Market Demand to Breeding Decisions: A Framework*. Lima, Peru: CGIAR Gender and Breeding Initiative.
- Rashid S and Zhang X (2019) *The Making of A Blue Revolution in Bangladesh: Enablers, Impacts, and the Path Ahead for Aquaculture*. Washington, DC: International Food Policy Research Institute (IFPRI).
- Reardon T (2015) The hidden middle: The quiet revolution in the midstream of agrifood value chains in developing countries. *Oxford Review of Economic Policy* 31: 45–63.

- Reardon T and Timmer CP (2012) The economics of the food system revolution. *Annual Review of Resource Economics* 4(4): 224–263.
- Renkow M and Byerlee D (2010) The impacts of CGIAR research: A review of recent evidence. *Food Policy* 35: 391–402.
- Ricciardi V, Ramankutty N, Mehrabi Z, et al. (2018) How much of the world's food do smallholders produce? *Global Food Security* 17: 64–72.
- Rutsaert P and Donovan J (2020) Sticking with the old seed: Input value chains and the challenges to deliver genetic gains to smallholder maize farmers. *Outlook on Agriculture* 49: 39–49.
- Rutsaert P, Donovan J and Kimenju S (2021) Demand-side challenges to increase sales of new maize hybrids in Kenya. *Technology in Society* 66: 101630.
- Sae-Lim P, Gjerde B, Nielsen HM, et al. (2016) A review of genotype-by-environment interaction and micro-environmental sensitivity in aquaculture species. *Reviews in Aquaculture* 8: 369–393.
- Samberg LH, Gerber JS, Ramankutty N, et al. (2016) Subnational distribution of average farm size and smallholder contributions to global food production. *Environmental Research Letters* 11: 124010.
- Scoones I and Thompson J (2011) The politics of seed in Africa's Green revolution: Alternative narratives and competing pathways. *IDS Bulletin* 42: 1–23.
- Shamsuzzaman MM, Xiangmin X and Islam MM (2016) Legal status of Bangladesh fisheries: Issues and responses. *Indian Journal of Geo Marine Sciences* 45(11): 1474–1480.
- Shikuku KM, Tran N, Joffre OM, et al. (2021) Lock-ins to the dissemination of genetically improved fish seeds. *Agricultural Systems* 188: 103042.
- Soullier G, Demont M, Arouna A, et al. (2020) The state of rice value chain upgrading in West Africa. *Global Food Security* 25: 100365.
- Spielman DJ, Hartwich F and Grebmer K. (2007) Sharing science, building bridges, and enhancing impact: Public-private partnerships in the CGIAR In: *IFPRI Discussion Paper 00708*. Washington, DC: The International Food Policy Research Institute (IFPRI).
- Spielman DJ, Hartwich F and Grebmer K (2010) Public-private partnerships and developing-country agriculture: Evidence from the international agricultural research system. *Public Administration and Development* 30: 261–276.
- Spielman DJ and Kennedy A (2016) Towards better metrics and policymaking for seed system development: Insights from Asia's seed industry. *Agricultural Systems* 147: 111–122.
- Spielman DJ and Smale M. (2017) Policy options to accelerate variety change among smallholder farmers in south Asia and Africa south of the Sahara In: *IFPRI discussion Papers 1666* Washington, D.C: International Food Policy Research Institute (IFPRI).
- Staudacher P, Brugger C, Winkler MS, et al. (2021) What agro-input dealers know, sell and say to smallholder farmers about pesticides: A mystery shopping and KAP analysis in Uganda. *Environmental Health* 20: 100.
- Stoian D, Donovan J, Elias M, et al. (2018) Fit for purpose? A review of guides for gender-equitable value chain development. *Development in Practice* 28: 494–509.
- Stuart AM, Devkota KP, Sato T, et al. (2018) On-farm assessment of different rice crop management practices in the Mekong Delta, Vietnam, using sustainability performance indicators. *Field Crops Research* 229: 103–114.
- Sumberg J, Keeney D and Dempsey B (2012) Public agronomy: Norman borlaug as 'brand hero' for the Green revolution. *The Journal of Development Studies* 48: 1587–1600.
- The World Bank (2016) *Vietnam - Sustainable Agriculture Transformation (VnSAT) Project : Procurement Plan for Goods and Works*. Washington, D.C: World Bank Group.
- Thiele G, Dufour D, Vernier P, et al. (2020) A review of varietal change in roots, tubers and bananas: Consumer preferences and other drivers of adoption and implications for breeding. *International Journal of Food Science and Technology* 56: 1076–1092.
- Tin HQ, Cuc NH, Be TT, et al. (2011) Impacts of seed clubs in ensuring local seed systems in the Mekong Delta, Vietnam. *Journal of Sustainable Agriculture* 35: 840–854.
- Tin HQ, Loi NH, Bjornstad Å, et al. (2021a) Participatory selection of CWR-derived salt-tolerant rice lines adapted to the coastal zone of the Mekong Delta. *Crop Science* 61: 277–288.
- Tin HQ, Loi NH, Labarosa SJE, et al. (2021b) Phenotypic response of farmer-selected CWR-derived rice lines to salt stress in the Mekong Delta. *Crop Science* 61: 201–218.
- Tran N, Shikuku KM, Rossignoli CM, et al. (2021) Growth, yield and profitability of genetically improved farmed tilapia (GIFT) and non-GIFT strains in Bangladesh. *Aquaculture* 536: 736486.
- Tripp R, Hu R, Pal S (2010) Rice seed provision and the evolution of seed markets. In: Pandey S, Byerlee D, Dawe A, et al. (eds) *Rice in the Global Economy: Strategic Research and Policy Issues for Food Security*. Los Banos, Philippines: International Rice Research Institute (IRRI), 213–230.
- Tripp R and Pal S (2001) The private delivery of public crop varieties: Rice in Andhra Pradesh. *World Development* 29: 103–117.
- Tripp R and Rohrbach D (2001) Policies for African seed enterprise development. *Food Policy* 26: 147–161.
- Tschirley D, Snyder J, Dolislager M, et al. (2015) Africa's unfolding diet transformation: Implications for agrifood system employment. *Journal of Agribusiness in Developing and Emerging Economies* 5: 102–136.
- USAID (2016) USAID, Early Generation Seed Investment Plan Guide, Washington, DC, <https://www.agrilinks.org/sites/default/files/resource/files/EGS%20Investment%20Plan%20Guide%20-%20Final.pdf>
- van Etten J, de Sousa K, Aguilar A, et al. (2019) Crop variety management for climate adaptation supported by citizen science. *Proceedings of the National Academy of Sciences* 116: 4194–4199.
- Van Mele P, Bentley JW and Guèi RG (2011) *African Seed Enterprises: Sowing the Seeds of Food Security*. Rome, Italy: CABI Publishing.
- Vos R and Cattaneo A (2021) Poverty reduction through the development of inclusive food value chains. *Journal of Integrative Agriculture* 20: 964–978.
- Walker TS and Alwang J (2015) *Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa*. Oxfordshire, UK: CGIAR - CABI.
- Worku M, De Groote H, Munyua B, et al. (2020) On-farm performance and farmers' participatory assessment of new stress-tolerant maize hybrids in Eastern Africa. *Field Crops Research* 246: 107693.