Identifying the gaps and opportunities for research in cowpea seed systems in Mali

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The overall purpose of this rapid scoping review of the cowpea seed sector in Mali is to identify with seed actors the current challenges in the sector and generate a pathway for strengthening it in the near future. This scoping review focuses on Mali, recognizing that cowpea production in West Africa in general is important and engagement of the international actors will also elaborate general issues in the cowpea seed sector for the immediate region. The objectives of the scoping study were to 1) identify, review, and document past and current initiatives on cowpea seed systems in Mali at the organizational level and 2) determine appropriate gaps for research institutions and develop a research theory of change.

Agronomic Overview

Cowpeas (Vigna unguiculata) are an important legume in cropping systems in West Africa and about 70% of cowpea production occurs in the drier Savanna and Sahelian zones. In Mali, cowpea production makes up 19% of the legume market (AGRA 2019b) and is usually intercropped with pearl millet or sorghum to improve nitrogen uptake (AGRA, 2019b) and because it is well suited to low input labor-intensive cultivation (Kamara et al. 2018). It is less frequently monocropped, or intercropped with maize, cassava, or cotton (Langyintuo et al., 2003) (Timko et al., 2007). An extensive chapter on improving cultivation of cowpea in West Africa by Kamara et al. (2018) reviews management challenges in intercrops and sole crops and indicates focus on IPM, nutrient management, plant configuration and population, and availability of water would improve production. Research from Nigeria on intercropping cowpea showed higher LER (land equivalent ratio) and other competitive indices values indicating sorghum cowpea intercrops resulted in higher income and better land use efficiency (Oseni, 2010). Cowpea is primarily produced by women (Masegela and Oluwatayo, 2018) and is an important food security crop in Mali and the region.

There are multiple biotic and abiotic stresses that cause challenges for smallholder farmers and cowpea varieties that have resistance would improve productivity, but one of the major challenges is the lack of varieties that are resistant to insect and disease pressures (Feed the Future Legume Innovation Lab, 2018). The most significant cowpea pest pressures include cowpea pod borer (*Maruca vitrata*), coreid pod-bugs (*Clavigralla tomentosicollis Stal* and *Anoplocnemis curvipes*), the groundnut aphid (*Aphis craccivora* Koch.) and thrips (*Megalurothrips sjostedti* Trybom) (Feed the Future Legume Innovation Lab, 2018). At early growth stages, cowpea is especially vulnerable to weeds, and two common problems are the parasitic weeds *Striga gesnerioides (Willd.) Vatke and Alectra vogelii (Benth.)* (Horn et al., 2015) that are common in low-fertility soils and survive for more than 20 years in the soil (Dugie et al. 2009). Abiotic stresses included low soil fertility (Feed the Future Legume Innovation Lab, 2018), erratic rainfall, high soil temperatures and degraded fragile soils (Coulibaly et al. 2010) and many fields do not reach their full potential because of a lack of improved varieties (Horn et al. 2015).

Two common solutions for low yields due to biotic and abiotic stress are a) appropriate pesticides and fertilizers combined with optimized management practices and b) improved varieties with resistance. However, many farmers lack access to affordable, accessible, and environmentally safe chemicals to defend against these stresses (Feed the Future Legume Innovation Lab, 2018). Furthermore, small scale farmers lack access to quality seed and the availability of quality seed is low for various reasons, including seed distributors are located in more populated areas and removed from where most producers live (Kone et al., 2020). While these challenges exist for men and women alike, women are the primary cowpea producers. Their limited access to capital, information, and greater distances to seed markets may be an additional burden, especially if they have limited mobility or higher labor demands in the household. In addition, these abiotic stresses may be compounded in women's fields, who often receive land allocations last; these tend to be lower or poor-quality fields. Finally, even when improved varieties are available, they may not have the quality attributes that are desirable to the producers and processors of the crop.

Cowpea seed access and availability

Evidence to date from Mali indicates most cowpea seed is acquired through trading and barter with neighbors and relatives or at food markets. Recent seed system studies have found that nearly 80% of seed comes from the informal or integrated seed sector (ISSD, 2014; (Smale et al., 2018), and Bazile (2006) indicated that 90% of seed exchanged comes from traditional seed systems in Mali. Of the certified seed that does exist, the national seed service provides the majority of the certified seed (O. Coulibaly et al. 2010). As has been found in numerous studies on the effectiveness of the formal system, in West Africa, the formal system of supplying the market with certified seed is not effective due to many factors, including "the difficulty of estimating the seed demand and supply; low purchasing power of farmers; low yield of varieties proposed by research; lack of qualified staff to ensure quality control and certification; lack of market to sell the surplus production generated by seeds, etc.," (Niangado 2010). However, it is worthy to note that farmers are willing to pay a premium for higher quality seed, but the magnitude of this premium has been shown to be less than the current price differential between certified seed and grain (Maredia et al., 2019).

Coulibaly et al. (2010) summarized that many smallholder farmers rely on the informal network and their own seed, thus failing to need to adopt certified seed varieties. Unfortunately, in some areas this may have led to the breakdown of the informal seed system, because the current varieties farmers are using may not be as adapted as previously to the new harsh, and rapidly changing growing conditions in which large-scale crop failures have occurred. In the same study, Coulibaly et al. (2010) also found that while no seed was available at the weekly markets examined by the researchers, people knew and trusted certain vendors that had grain suitable for seed.

Several projects have focused on cowpea seed systems or issues related to seed in Mali in the past 15 years.

Table 1.1 Seed Projects over the past 15 years in Mali and region

Projects	Overview
FTF LIL, 2018	With the support of the Legume Innovation Lab (LIL), Scientific Animations Without Borders (SAWBO) creates animated videos to educate producers and communities on seed storage techniques as well as other management practices.
West Africa Seed Program (WASP, 2017)	[2012-2017] This project includes Mali and focuses on improving production and maintenance of quality seed. There is not a specific focus on cowpea or Mali.
The West African Agricultural Productivity Program (WAAPP, 2018)	[Years: unclear] This program is part of CORAF. This program funds seed production and variety release in Mali. This program is funded (at least in part) by the World Bank.
Alliance for a Green Revolution in Africa (AGRA) (AGRA, n.d., 2019b)	[Years: unclear] In Mali, AGRA is specifically focusing on the development of core agricultural systems for cowpea, rice, and maize. This system includes seed, extension, markets, etc.
Sasakawa Africa Association (SSA) (www.ssa-safe.org)	[Years: unclear] This organization has a variety of programs, some specific to Mali, focused around Crop Productivity Enhancement, Postharvest, Market Access, Education, and other areas. Uses the community seed multiplication model
Plan de campagne agricole 2016-2017 du Mali	(Ministere de l'agriculture & Ministere de l'elevage et de la peche, 2016) This project focuses on training cowpea agricultural organizations and supporting women in disseminating cowpea production techniques. It invests in providing more certified seed, training processors in cowpea food technologies, marketing support, conservation product support, and small processing equipment support.

Gender and cowpea seed systems

Women in African and indigenous cultures typically have knowledge about seeds and seed varieties, as well as traits suitable to their cooking preferences and storage quality (Almekinders & Louwaars, 2002). To a large extent, this knowledge has been ignored or overlooked. There is limited data specifically on cowpea seed systems and women in Mali. Cowpeas are predominately cultivated and processed by women (Masegela and Oluwatayo, 2018) and is often a women's enterprise {Citation} and they rely heavily on their social networks within the family and community to acquire cowpea seed when needed. The barriers to access to improved varieties of a key food security crop that also garners a higher price than most grains, and is important in social traditions (Kouyate et al. 2021) are high: women are generally less likely to have access to formal markets, less likely to have resources to purchase new seed and the sometimes requisite inputs associated with improved cultivars, historically less likely to be targeted and included in breeding efforts, and culturally less likely to have access to extension, thus limiting their exposure to and ability to acquire improved cowpea seed. Furthermore, ethnographic evidence from rural Mali indicates that social and cultural patterns in Bamana

culture: “lead to a gender-biased system of access to commercially viable productive resources” (Wooten, 2003) in which women are limited from these endeavors.

Women’s access to credit or income is also limited in West Africa, and women in Mali, Niger, and Nigeria generally do not have control over their productive assets or on-farm income (Adetonah, Nouhoheflin, and Aitchedji, 2010). This limits their ability to purchase seed and women reported they needed credit in order to purchase seed (Adetonah, Nouhoheflin, and Aitchedji, 2010). Likewise, little access to credit or income reduces the likelihood of using more expensive insecticides or other chemicals for both production of improved seed, management of the crop, and storage of the crop. In two studies in West and Central Africa countries, results indicated that women were more likely to adopt PICS bags ((Moussa et al., 2014) and in Mali, women did not have access to insecticides for storage so they used other technologies, such as solar drying (Adetonah, Nouhoheflin, and Aitchedji, 2010).

Cowpea is an essential crop cultivated by women in Mali for the family’s food and nutritional security and it is used for household consumption and as a source of income for women through market sales. Thus, any seed access initiatives should focus on supporting their involvement and livelihoods and doing “no harm” to that livelihood (Ashby and Polar, 2019). The TL-III Innovation Platform established at Cinzana to increase the availability of improved cowpea seed involved both men and women in the platform (Kouyate et al. 2021) and had multiple avenues for engagement. However, there were only 185 women out of 1097 participants in the trainings that aimed to increase access to knowledge and advisory services whereas 2533 women out of 2934 producers participated in the demonstration trials and 726 women out of 1866 participated in field days. The majority of people that received trainings were men but only 400 men were present at the demonstration trials. There are social and cultural constraints in Mali to the participation of women in numerous types of services and this project did provide different forms of engagement (training vs demonstrations vs field days) that were more accessible either logistically or culturally to women. However, while women may be more able to attend demonstration plots in field days than traveling to centers for training, they are also as in need or more so of the knowledge exchange and advisory services. This demonstrates the challenges associated with projects aiming to increase the availability of seed for a crop vital to women: men often become the main recipients of a process of increasing the availability of improved seed that requires additional inputs and purchasing power. It is imperative that efforts to improve access and availability of seed do so equitably without causing harm to already disenfranchised groups.

Women also play a key role in the marketing and purchasing of cowpeas. Female vendors (who are also farmers) sell grain suitable for seed and weekly markets and have trusting relationships with customers, who value their seed quality (Coulibaly et al. 2010). Women handle most of the cowpea green pod marketing, and women harvest and sell cowpea directly to customers on roadsides (Okike et al., 2001).

Early generation seed and varietal development roles in cowpea seed systems in Mali

The public sector in Mali produces foundation seed and has had support from AGRA (AGRA, 2019). Even though foundation seed was produced for cowpea (as well as many other crops) in

Mali, foundation seed production for released varieties was only 19% for cowpea (and similar rates for other crops). Foundation seed is mainly accessed by farmers through the research station (IER), extension services, or NGOs (Heemskerk et al., 2017). The Regional Agronomy Research Center (CCRA) in Mali creates new seed varieties, which are then approved by LaboSem. IER is also listed as creating, introducing, and improving varieties (Coulibaly et al., 2014). At least 18 new cowpea varieties were developed by ISRA-Senegal, INERA-Burkina Faso, SARI-Ghana, and URC (Feed the Future Legume Innovation Lab, 2018).

Variety development lies within the remit of IER (Institut d'Economie Rurale). The Service National de Semences (SSN) falls under the DNA and is responsible for implementing the National Seed Plan. IER provides SSN with the basic seeds for reproduction and the SSN has seed multiplication sites (Coulibaly et al., 2014). The Association Semencière du Mali (ASSEMA) is the national seed association and brings together the seed producers under one umbrella (Waithaka et al., 2019). The varieties and lines for breeding come from research centers, local germplasm, and seed farmers from neighboring countries (Burkina Faso and Nigeria). IITA has switched their attention from monocrop-adapted cowpea lines to intercrop-adapted lines. They also focus on incorporating genes for resistance to pests and diseases and with consumer-preferred traits (seed coat color, rough seed coat texture and larger seed size) (Coulibaly et al., 2010).

Varietal replacement, release and adoption rates of cowpea in West Africa

The average age of varieties is an indicator of seed replacement or how often farmers are buying and replacing seed. Farmers replace varieties when they have poor seed quality, reduced yield, lost stored seed, increased susceptibility to pest, or low or no germination. They may also replace them if new varieties are available and meet their growing and processing needs. The average age of current cowpea varieties is about 15 years old, with only three varieties under diffusion since 2016 (Waithaka et al., 2019). According to Coulibaly et al., (2010) an "estimated 10% of Mali's millet and cowpea area and less than 20% of its sorghum area has been planted with certified seed." However, it is unclear how much certified seed is produced, with information depending on sources (Haggblade et al., 2015).

Varieties released

Association of Farmers' Organizations in Mali (AAOP) or seed producer cooperatives, disseminate improved varieties and takes note of problems of farmers (Coulibaly et al., 2014). Dugje et al. (2009) listed cowpea varieties recommended for Mali and the Feed the Future Legume Innovation Lab (2018) developed and released 93 new bean and cowpea varieties (at least 18 cowpea varieties). These varieties are high yielding and resistant to a variety of significant biotic and abiotic pressures. The varieties were developed for the following traits: cowpea aphid resistance, flower thrips resistance, and pod-sucking bug resistance. From IITA, six nematode resistant varieties were developed and released. (varieties CE-31, Frade Preto, CE-28, CE-01, CE-315 and CE-237) (Oliveira et al., 2012) and earlier other Striga gesnerioides and Alectra vogelii tolerant varieties were developed and released (Kabambe et al., 2013; Timko et al., 2007).

In Mali, the following varieties are popular: Dounafana, Yerewolo, Sankaraka, Korobalen, TN88-63, GoromGorom (Ministere de l'agriculture and Ministere de l'elevage et de la peche, 2016) and these varieties were listed in the 2013 official catalog (although they were released before 2013): Korobalen (IT89KD-374), Sangaraka (IT89KD-245), Djemani (PBL 22), Yerewolo (PRL 73), Dounan fana (Walker and Alwang, 2015). According to Dr. Diallo Sory (2020) cowpea breeder at Cinzana, the following varieties were under diffusion at seed fairs: WILIBALI (IT90K-372-1-2) dif 2002 (introduction 1996), ACAR -1 (IT89KD-245) dif 2016, SIMBO (CZ06-2-17) dif 2016, Jiguifa (CZ06-1-12). In June of 2014, Mali's national seed laboratory (Laboratoire National des Semences (LABOSEM)) approved eight varieties of cowpea, fonio, millet, and sorghum produced by farmers. This was accomplished through Biodiversity International's work in Mali ("Farmer-selected local varieties certified in Mali," n.d.). In 2010, IT97K-499-35 (includes Striga resistance) and IT93K-876-30 were two new varieties released in Mal. In 2010, IT97K-499-35 (includes Striga resistance) and IT93K-876-30 were two new varieties released in Mali and in 2013, there were only 27 varieties listed in the official catalog and the number of varieties in distribution from 1979-2010 was 14 (Boukar et al., 2019). Adoption rates are variable based on time, location, and multiple other factors. Rather than measuring local adoption rates at one time, adoption rates should be assessed by trends over a long period of time and space (Haggblade et al., 2015).

There are several other examples of cowpea breeding in Mali and regionally. In 2006 and 2007, 91 cowpea varieties were screened for tolerance to drought and researchers identified four lines as good combiners to generate improved cowpea varieties (Olubunmi, 2015). In Burkina Faso, 108 cowpea genotypes in 2007 for *Striga* resistance, and five genotypes were identified for resistance to all three *Striga* races and Resistant varieties were bred until F2 in 2008 and 2009 (Tignegre, 2010).

Known varietal preferences

Producer and consumer preferences may vary by the individuals' roles in the production, processing, and marketing of the crop, the size of landholdings, and the intended use (home consumption, marketing, multi-purpose, etc.). In addition, cowpea is valued not only for the grain/seed but for the leaves and green pods which are harvested throughout the season for consumption in rural households. There are limited studies on trait preferences in Mali specifically, although there are comparable studies in the region (Feed the Future Legume Innovation Lab, 2018; Ishikawa et al., 2020; Mishili et al., 2009). As discussed by Ishikawa et al. (2019) in a study assessing trait preferences in Burkina Faso, reports on farmers' cowpea selection criteria and farmer participation in breeding programs in the region are also very limited.

Research conducted in Ghana, Mali, and Nigeria, determined the impact of cowpea grain quality characteristics on market price (Mishili et al., 2009). The research aimed to understand consumer preferences to develop the market more effectively for cowpea and they found that larger cowpea size is preferred by most consumers, and other qualities vary in preference by local market but customers in all three countries are willing to pay a premium for large cowpea grains (Mishili et al. 2009).

The FTF LIL found in Senegal and Zambia that cowpeas with green pods, green shelled peas and leaves were preferred by consumers; for these qualities, harvest should occur before the dry grain is mature (during the "hunger period") (Feed the Future Legume Innovation Lab, 2018). There are differences in preferences across the region. For example, at least 18 cowpea varieties were developed to increase grain size and whiteness, two traits preferred by consumers in Nigeria, Ghana, and Senegal but in Mali, evidence suggests that consumers prefer brown or white seed coat color, rough seed coat texture, and large seed size, although the rise of urbanization has changed cultural taste and acceptability of cowpea, because more people are favoring imported food over domestic food (Coulibaly et al., 2010).

Males and females had different preferences for cowpea varieties across the region (Abudulai et al., 2016). Most farmers grow cowpeas in intercropped systems, which can require unique plant architecture and other traits than varieties grown in a monocrop. In Ghana, participatory work with cowpea farmers identified preferred varieties during development and varieties selected by farmers were not necessarily highest yielding, they also considered other factors such as seed coat and cost (Abudulai et al., 2016). In Mali, there are likely similar issues with preferences and the involvement of different types of growers in the selection process would be beneficial. The FTF LIL also reported on the development of varieties that are specifically advantageous to smallholder women producers, who generally grow beans and cowpea under marginal conditions. These traits include disease, drought, and high-temperature resistance, as well as resiliency in low fertility soils (Feed the Future Legume Innovation Lab, 2018).

Identified challenges in cowpea seed systems

The research on cowpea seed systems in Mali over the past 15 years indicate the challenges in cowpea seed systems are similar to known challenges in many food security crops that have low priority for breeding and management programs. Many of the challenges also link to known limitations of farmer adoption of new technologies and gender inequities, whether they are varieties or other climate smart technologies. For example, in a recent scoping study published in Nature, the review found that the main factors that limit farmer adoption of climate smart technologies included access to resources, information, and appropriateness to the environment and socio-economic context (Acevedo et al. 2020). The access and availability to improved cowpea seeds face similar issues, in addition to policy and delivery hurdles. Efforts over the past 15 years in cowpea seed systems in Mali and West Africa have focused on seed storage (Moussa et al. 2014), education (Feed the Future Legume Innovation Lab, 2018), policy, and seed production.

Lack of affordable storage

For both formal and informal seed systems, adequate storage for seed is essential for maintaining seed quality (germination, viability) and protecting stored seed from insect damage. Besides PICS bags, there are relatively few options for safe, affordable storage for farmers. Plastic jugs are used increasingly for storing small amounts of cowpea, while simple bags, metal jugs, and similar containers are also used (Moussa et al. 2014). Without adequate storage, grain losses increase, and farmers lose additional income. Weevil (bruchid) *(Callosobruchus maculatus)* can infest cowpea storage and lead to total grain loss (Dugje et al., 2009) and adult beetles lay eggs on pods or in seeds. The most important factor in adoption in PICS villages in Mali was

availability (both in quantity and during the proper time); thus, proper implementation was suggested (Moussa et al. 2014). The second most important factor (of a lack of adoption in non-PICS villages) is lack of knowledge but cost was a relatively insignificant factor in adoption (Moussa et al. 2014).

Baoua et al. (2013) found that SuperGrain bags are comparable to PICS bags and can also be used to store cowpea, although PICS bags cost less, are more accessible, and have greater durability over multiple growing seasons. In response to a lack of affordable storage options as well as a lack of adequate adoption and education, additional pesticides are often used when storing cowpeas (Moussa et al. 2014).

Lack of available, accessible, and affordable quality seed

Within Africa in general, research on farming willingness to purchase legume seeds has shown mixed evidence. Maredia et al. (2019) determined from Integrated Surveys on Agriculture available from Ethiopia, Nigeria, Niger, Tanzania, Uganda, and Malawi that less than 5% of seed was purchased for legume crops such as common bean, cowpea, pigeon pea, and fava bean. However, McGuire and Sperling (2016) found that 64% of legume seed was obtained from the local market. In a recent report from the FTF LIL (2018) scientists tested seed access models, determined factors that increased seed cost and factors that decrease seed quality for farmers in marginalized areas. This study found that smallholder farmers are willing to pay extra for quality seed and that community-based multiplication systems can produce quality seed (with sufficient support and training).

In a policy brief specific to WCA, Djamen (2016) explained multiple inefficiencies in the formal seed sector relating to certified seed. Some of the most important points were that there is a large and poorly characterized demand for quality seed, the response capacity of the seed system is low, subsidies' policies have not been effective, traditional varieties have not been integrated into the formal seed systems, and the disengagement of the State. Furthermore, Djamen (2016) identified major concerns of WCA smallholder farmers regarding access to quality seed, including availability of adapted varieties suitable to the farmers' growing objectives, research doesn't prioritize varieties that require few external inputs, and access to related support services.

Varieties adapted to local conditions

Because Mali has 49 agro-ecological zones, locally-adapted varieties are needed to favor these specific conditions (Smale et al. 2010). In a baseline impact assessment of Bt cowpea in West Africa, Coulibaly et al. (2010) noted there was no clear reason why adoption of certified cowpea seed among farmers was low but it was generally noted that information exchange and awareness were important for widespread adoption, and they concluded that the seed certification process was too lengthy. In rice systems, the demand for improved seeds is generally higher in irrigated areas than in rainfed areas because the availability of water controls the response of new varieties to fertilizer inputs (Dalohoun et al. 2011).

Misinformation or lack of information on improved technologies of cowpea

The lack of information about new varieties, the low willingness to try new varieties without first seeing them grow, and the near nonexistent extension programs linked to the NARS lead to misinformation and low use of improved technologies. Coulibaly et al. (2016) found that farmers

working directly with research or extension institutions typically received accurate information about cowpea production technologies and have access to improved seed. But farmers interacting indirectly with these institutions lack sufficient/accurate information sharing due to many factors/barriers such as educational, cultural, socioeconomic, political, and institutional.

Lack of policy support

Cowpea and groundnut are both grown by women in Mali and their resources for agricultural inputs and access to information about new varieties and seed is limited. Furthermore, cowpea development in general is not a priority for the government and subsidies are limited or not available (Coulibaly et al. 2016) and policy is often more focused on formal seed systems in which conversations don't directly involve smallholder producers (Smale et al. 2018). Djamen (2016) outlines "six strategic outcomes to be achieved for the development of the seed sector in WCA: Coherent seed policies are implemented, an efficient mechanism for governance of the sector is put in place, seed markets are less fragmented and more attractive, the R-D scheme is more efficient and in line with the demand, adapted funding is available to actors, and empowerment of the actors is improved."

Other challenges presented by stakeholders

From conversations with plant breeders and agro-dealers, evidence suggests that quality seed multiplication, production, and distribution are lacking for the cowpea seed sector in Mali. In addition to the fact that there are few newly developed varieties that are adapted to the growing environments. While seed that is produced and sold by agro-dealers may be available, again, it is available in city centers and far from the actual growers, most of who are women with serious resource and time constraints. Agro-dealers also face the risk of unsold seed and estimating demand continues to be a hurdle in the sale of self-pollinated seed that is easy to save from year to year.

Other research suggests that the cowpea projects focused on Mali, Niger, and Nigeria, develop innovative solutions and improved varieties, but have an ad-hoc nature and thus fail to spread and disseminate these innovations (Coulibaly et al. 2010). They indicated that funds are generally being given in the wrong areas of cowpea commodity improvements. International donors provide most of the funds, but they lack commitment of local policymakers. In general, less funds are going to cowpea research and development, versus other crops. In addition, international donors focus more on breeding rather than dissemination of results. Finally, government agencies are responsible for this dissemination but lack the funds and support to do so effectively.

Identified opportunities for improving seed systems

Village-level demonstrations and implementation

Research on cowpea seed adoption and other crops have shown that demonstrations that include farmers in the process and allow visual and practical access to the technology improves the utilization. Direct interaction with producers through village-level demonstrations of PICS bags was found to be one of the most important factors in adoption (Moussa et al. 2014). This allows producers to receive accurate knowledge on the use of PICS bags as well as knowledge on their benefits. PRONAF (funded by IFAD) proposed a program that uses participatory methods to

introduce and disseminate improved cowpea varieties and integrated production technologies would be ideal (ex: IPM technologies developed by IITA and NARES) (Coulibaly et al. 2014). From research on participatory plant breeding with sorghum in Mali, there is strong evidence that even with demonstration plots and information exchange, adoption of new varieties takes 3-5 years of exposure (Isaacs et al. in review). Thus, longer-term funding projects or partnerships with local organizations that support demonstration trials and promotion may improve adoption. Furthermore, cowpea innovation projects need to focus more on spreading, disseminating, and applying the technology they develop (Coulibaly et al. 2014) rather than moving onto the next project.

Impact pathways and assessments

The Feed the Future Legume Innovation Lab (2018) research development strategy helped scientists define clear project goals and pathways to achieve their goals and scaling with partners related to cowpea seed varietal development and information dissemination. This strategy allowed projects to be more effective and impactful. Coulibaly et al. (2010) also suggested that research assessments (through ex-ante impact reports) need to be updated by national research and IITA so that the most pressing opportunities and threats to cowpea production can be prioritized.

Policy focus on informal and integrated seed systems

As pointed out by Almekinders and Louwaars (2002), rather than focusing policy on formal seed systems, attention should be given to informal seed systems, and especially the connections between the two, such as modeled in the Integrated Seed Sector Development Platform (Louwaars et al. 2013) and recommended by Coulibaly et al. (2014) so that farmers can afford and have access to quality seed. Formal seed systems alone do not reach remote or poor farmers nor do they deliver the portfolio of varieties needed by these populations (Sperling et al. 2020). The policies that regulate seed systems are designed to augment the formal system and in fact, challenge the very existence of seed, as it is only "seed" if it is registered and sold as stipulated (Sperling et al. 2020). Furthermore, government intervention mechanisms (in research and extension) need to be monitored and evaluated so that policy can better support farmers (Coulibaly et al. 2010). The Tropical Legume III Innovation Platforms in Nigeria successfully generated strategies for strengthening the cowpea seed sector with an integrated approach. They bridged farmer cooperatives, traders, processors, women's groups, seed companies, individual entrepreneurs and research institutions, among others, to strengthen community-based seed production and link the producers with seed companies, while seed companies linked with research institutions for early generation seed (EGS) (Lorlamen et al. 2021).

Effective seed multiplication and distribution systems

Effective seed multiplication and distribution systems remain a problem for most legume crops. One method proposed (and implemented for sorghum in Mali) is a program that improves seed multiplication and diffusion systems with Malian farmers' associations or cooperatives to help test and promote certified seed in order to increase accessibility of improved seed for farmers (Coulibaly et al. 2010; Coulibaly et al. 2014). Coulibaly (et al. 2014) also indicates for cowpea seed systems that farmers need to have access to marketing devices and reliable product markets – in other words, promotion of cowpea as a valuable and nutritious crop for food security and poverty reduction would increase the value of the crop in the commodity chain. Other markets

have been liberalized more successfully than the traditional sorghum, millet, and cowpea crops preferred in the region.

As outlined by Haggblade et al. (2015) seed systems in general in Mali are in a state of transition, with the involvement of the state in the processes of production, certification and distribution fading, and the rise of three distribution models: the informal in which farmers exchange and save their own seed based on selection criteria based down for generations, the public sector with extension services and agricultural development programs, and private companies. The cowpea seed sector is primarily situated in the informal, with agricultural development organizations and the NARS involved to varying degrees. In 2015, 1% of cowpea seed was commercialized and 1%, or 32 tons of R1 and R2 were sold as certified seed (Haggblade et al. 2015).

Decentralized seed production is an opportunity for improving the spread of information, and the availability and distribution of improved varieties. With sorghum and millet, Coulibaly et al. (2014) advocated for enhancing the link between types of seed networks to increase the dissemination of improved varieties. The authors indicated three improvements, including maintaining satellite seed producers as producers/distributors of R1 seeds, the SSN staff should be reduced, and the AOPP staff should be increased to enable more coverage to farmers. Furthermore, varietal diversity initiatives should be more accessible for farmers and improved seed should be sold at an affordable price. These considerations would likely transfer well within cowpea seed systems. Furthermore, Abudulai et al. (2016) found that working with farmers to identify preferred cowpea cultivars with desired insect and disease resistance accelerated their dissemination.

An example of an integrated seed system approach to multiplication and distribution of improved seed systems was an innovation platform established in 2016 at Cinzana Agronomic Research Station as part of the TL-III project. The objective was to improve and increase the production and distribution of cowpea seeds in Mali (Kouyate et al. 2021). This platform used a market information systems approach in order to "(1) exchange and share information, (2) build social capital and trust, and (3) create a framework or conducive environment for innovation." It consisted of numerous stakeholders from seed producer cooperatives, seed producers, NGOs, seed companies, an agro-dealer, radio networks and researchers, including representation from women. The platform established a governance structure and included activities such as workshops, trainings, and increasing seed supply. In Mali, professional seed growers can produce basic seed provided they have the technical capacity and thus the platform enabled increased production of early generation seed and multiplication of certified seed across sectors (including NGOs and individuals). While there were numerous challenges as outlined in Kouyate et al. (2021), certified cowpea seed production did increase during the period and there was increased distribution.

Outlook for research

Over the past 15 years, there have a handful of projects focused on enhancing cowpea seed systems in Mali. The major projects have focused on increasing training and demonstration trials with seed multiplication (TL-III), strategies for storage of cowpea, and supporting women in

disseminating cowpea production techniques. Evidence indicates that seed distributors and programs need to find economical strategies for improving the dissemination of improved varieties to smallholder farmers. Coulibaly et al. (2010) analyzed seed systems extensively and concluded that market and production constraints as perceived by the end users are not well understood and considerable research is needed. Issues of trust in terms of the quality and suitability of seed is an issue and research and development programs to address these factors are needed. There are gaps in our understanding of farmer seed networks, especially as pertains to cowpea, that would provide insights into how best to increase information flow and availability of improved seeds.

In Mali, there's limited detailed evidence on trait preferences for different market segments of cowpea, with limited differentiation between gendered roles in cowpea production, processing, and marketing. While some of this work has been done regionally, there is also clear evidence that these qualities and preferences vary within the region. New gender responsive tools developed by the CGIAR are currently in testing phases for common bean in Southern Africa, for cassava in Nigeria, and bananas in East Africa. Testing and/or employing a similar method for cowpea in Mali, to identify key breeding needs for the diverse environments, agroecologies, and market segments are short term strategies that should be implemented.

Legume crops in particular are highly vulnerable to insect attacks during storage and require extra safeguards in storage for seed maintenance, profitable marketing, and food security. Increased availability of technologies to reduce post-harvest losses are needed. Research on cowpea has shown not only that PICS are effective, but that women invest in low input technologies readily and adopted PICS quicker and with more frequency than men. Expanding access to PICS and advisory services about PICS is a quick pathway to improving seed security *and* food security in rural households. It also would provide small producers with the opportunity to save their cowpea production until market prices are advantageous.

Women and youth would be well served by the improvement of breeding objectives that meet household and market needs, increased availability of simple storage solutions, and increased access to advisory services and information about improved cowpea varieties. As in many smallholder conditions, women have extremely limited access to credit and markets that sell improved varieties. These structural issues must be addressed to advance women's and youth's opportunities for sustainable livelihoods. Simply increasing the supply or availability of improved cowpea varieties to men will severely impact women's control of a valuable crop that could serve as a platform for economic empowerment. Initiatives to multiply cowpea varieties and expand decentralized seed production should be oriented towards women and youth (not to the exclusion of men).

Current evidence from Mali indicates that decentralized seed production through innovation platforms and cooperatives are viable means for increasing certified seed stocks, expanding access to improved varieties in remote areas, and increasing the production of cowpea. Several researchers discussed the advantages of linking the public research and development entities with seed producing associations in rural areas. A potential model may include certified producers

that multiply seed of farmer preferred breeding lines and are supplied with early generation seed from IER or other entities. However, the adoption of new varieties for crops that are traditionally saved and exchanged through social networks necessitates concentrated efforts that increase farmer exposure to the varieties through demonstration plots and field days over multiple years. Furthermore, the availability of a diversity of varieties that include local cultivars would not only support farmer innovation and the availability of varieties suited to environmental niches but would also help maintain genetic diversity and prevent the narrowing of the gene pool in-situ.

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