EXECUTIVE SUMMARY

The Tropical Legumes (TL) projects were implemented by three CGIAR centers (ICRISAT, CIAT and IITA) together with 15 national agricultural research system partners in sub-Saharan Africa (SSA) and South Asia (SA). These projects were implemented in three phases: TL Phase I (2007–2011, US$ 20.603 million), TL II Phase II (2012–2014, US$ 21.420 million) and Phase III or TL III (2015–2019, US$ 24.970 million). The projects aimed to improve the livelihoods of smallholder farmers in drought-prone areas of SSA and SA through improved productivity and production of six major grain legume crops – chickpea (*Cicer arietinum*), common bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), pigeonpea (*Cajanus cajan*) and soybean (*Glycine max*). The project activities were implemented in Burkina Faso, Ghana, Mali, Niger, Nigeria, Senegal, Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Uganda and Zimbabwe in SSA and India and Bangladesh in SA. The TL projects together with some of their precursors and complementary projects from other agencies facilitated the development of 304 improved legume varieties and the production of about 397,050 t (t) of certified seeds of the target legume crops in the focus countries. The certified seeds were planted on about 4.4 million hectares (ha) by more than 22 million smallholder farmers in the 15 countries and beyond, producing about 4.9 million t of grain worth US$ 2.6 billion.

While the TL and TL II projects focused on research and development activities in six target legume crops, TL III strategically focused on fewer crops (chickpea, common bean, cowpea and groundnut) and fewer geographies (Burkina Faso, Ghana, Mali, Nigeria, Ethiopia, Tanzania and Uganda; and Uttar Pradesh state of India). These also aimed to fundamentally strengthen breeding programs and seed platforms of the National Agricultural Research Systems (NARS) and CGIAR to enhance their ability to deliver high and sustained technology outputs to smallholder farmers. Capacity building remained an important component of the three phases. This report emphasises the achievements and challenges under TL III while making references to the status and progress under Phases I and II.

Guided by market-driven approaches to develop client preferred common bean varieties, significant efforts were made to address the production constraints and develop multi-trait varieties. To address the major production constraints, 104 common bean varieties were developed and released and 114,649 t of certified seed produced and planted on about 1.15 million ha. In Southern Tanzania, the variety Uyole 96 had been dominating for more than 60% of production; by 2016, it had been replaced by Njano Uyole that was appreciated for its agronomy, consumption, processing and marketing attributes such as better yield, pest/disease resistance, ease of shelling, storability, market price, color and cooking qualities. The technological progress in the form of varietal change and improved agronomic practices provided positive growth trends in common bean productivity in Ethiopia where the yield increased from 1.0 t/ha in 2008 to about 1.7 t/ha in 2016. The adoption of improved common bean varieties increased the average yield by 336 kg/ha. The national adoption rate of improved varieties in Ethiopia was about 37% of bean growers, which translates to about 1.5 million households. Mexican 142 that was controlling over 50% of the white canning bean market class and Red Wolayita that was controlling about 70% of the red cooking bean type at the time of baseline studies in 2009 have been totally replaced by new varieties promoted under the project.

Advances made under TL and associated projects led to a better understanding of the groundnut genome, discovery of genes/variants for traits of interest and the integration of marker-assisted breeding for selected traits. Under TL projects, a total of 101 groundnut varieties were developed and released where 110,695 t of certified seed were produced and planted on about 1.11 million ha by 2018. Improved groundnut varieties in Nigeria registered an overall adoption rate of 44% by farmers across project intervention areas. When the project started in 2007, old varieties such as Samnut 1 to Samnut 20 released between the 1960s and early 1990s were still dominant. The project promoted the adoption of Samnut 21, Samnut 22 and Samnut 23 released in 2000 before the release of newer varieties Samnut 24 (2011), Samnut 25 (2013) and Samnut 26 (2013) which have replaced these old varieties, with Samnut 24 currently account for about 25% of groundnut production. Project interventions and associated enabling factors including strategic partnerships led to a significant yield increase of 222.44 kg/ha (391 kg/ha for females and 200.5 kg/ha for males) and associated income increase of US$ 135/ha (US$ 168/ha for females and US$ 93/ha for males).

In Tanzania, adoption of improved groundnut varieties is estimated at 19% nationally. However, the seed systems work through about 400 farmer research groups linked to seed companies as contract seed producers, together with training and adoption of integrated crop management practices that have contributed to increased groundnut productivity from 724 kg/ha in 2008 to about 1010 kg/ha in 2015 and total production from 340,770 t on about 470,670 ha in 2008 to 1,635,335 t on about 1,619,500 ha in 2015. The change in production is about 480% over 2008 base figures, and both gains in area (244%) and productivity (39%) have contributed to these remarkable increases. The varieties that were reigning before 2007 include Nyota (1.5 t/ha), Johari (1 t/ha), Sawia (1.5 t/ha) and Pendo (1.5 t/ha). While Pendo is still dominant and is currently being replaced by rosette-resistant Nachgwea (1-1.5 kg/ha) and Mangaka (1.5-1.8 t/ha), the other varieties have largely been replaced. In Mali, the ruling varieties before 2007 were very old with some dating back to 1928. New varieties less than 10 years old were promoted by the project. Fleur 11 and ICGV 86124 are currently replacing the old ones because of their high fodder yield and their short duration in an area with rainfall shortage where most farmers prefer early-maturing varieties with high pod and haulm yields for livestock.

The cowpea team in TL projects aimed at developing drought-tolerant, phosphorus use-efficient, bacterial blight- and virus-resistant lines by exploiting available genetic resources and deploying modern breeding tools. These efforts led to a better understanding of genetics, genomics and breeding of cowpea and various abiotic and biotic factors affecting cowpea yield. Through the support of the TL projects, 31 cowpea varieties were developed and 29,169 t of certified seeds were produced and planted on about 729,227 ha. In Nigeria, old varieties such as Sampea 7, released in 1985, have almost been completely replaced by newer varieties such as Sampea 8 released in 2005 and promoted under the project since 2007. Moreover, Sampea 8 was quickly replaced by Sampea 11 released in 2009, which in turn is currently being replaced swiftly by Sampea 14 to Sampea 17. A detailed description of the ruling varieties being replaced in some countries and crops, the age and degree of replacement of ruling varieties in every case is presented in *Annex 1*.

In the face of diminishing rainfall and increasing temperatures globally, developing drought- and heat-tolerant chickpea varieties becomes imperative considering that chickpea is one of the important legume crops largely grown by smallholder farmers who are more susceptible to climate variability and change. Therefore, efforts were made to develop several early-maturing (drought escaping) varieties with

improved drought tolerance by selecting for grain yield under moisture stress conditions. During the three phases of the project, 28 chickpea varieties were developed and released, and 122,705 t of certified seeds of modern improved varieties were produced and planted on about 1.02 million ha. A study conducted in three intervention districts in Ethiopia showed adoption levels of up to 80% of new varieties, although recent surveys put the national average at 59%. Together with integrated crop management practices, chickpea productivity increased from 1.27 t/ha in 2007 to 2.06 t/ha in 2018; and total production rose from 253,871 t on about 200,066 ha to 444,146 t on about 225,608 ha in 2016. The change in production is about 93% over 2007 base figures, mainly accounted for by gain in productivity (62%) rather than increased area (21%).

To improve efficiency of breeding programs, broadening the genetic base (for tolerance to abiotic stresses); novel breeding approaches such as MAGIC populations; accurate high-throughput phenotyping; rapid generation turnover; efficient breeding data management system, and genomics-assisted breeding were emphasized in the project in collaboration with several other projects funded from international and national funding agencies. Several molecular breeding lines were developed and released using genome-based marker information for many traits in these legume crops. For instance, due to collaborative efforts of ICRISAT and its partners Ethiopian Institute of Agricultural Research and Indian Council of Agricultural Research, marker assisted backcrossing (MABC) varieties (Geletu and Pusa Chickpea 10216 (BGM 10216) were developed using MABC approach and released for commercial cultivation in Ethiopia and India, respectively. Similarly, in collaboration with University of Agricultural Sciences – Raichur, MABC-WR-SA-1 resistant for Fusarium Wilt has been released. Two groundnut molecular breeding varieties, namely Girnar 4 and Girnar 5, were developed with joint efforts of ICRISAT and Directorate of Groundnut Research, India as part of some related projects.

DNA fingerprinting work to support adoption data in collaboration with DArT Pvt Ltd in Australia for chickpea, groundnut and cowpea, and at CIAT headquarters in Columbia for common bean have faced various challenges. Final reports have not been submitted. The two ICRISAT gender scientists redeployed to the project in ESA and WCA have supported the national programs to run focused group discussions and surveys around gender yield gaps which reported no significant yield gaps. Recommendations from such studies have also been used to reorganize and strengthen seed systems approaches including multi stakeholder platforms (MSPs) as well as designing product profiles that respond to different stakeholders in the market.

All the 15 NARS partner crop breeding programs have in varying degrees embraced approaches that enhance breeding efficiency and accelerate genetic gains, such as the use of Breeding Management System (BMS) for field planning, data gathering and management; digital data collection tools; increasing the number of crosses, cycles per year, and test locations besides redesigning breeding and hybridization methods to include early generation screening. The programs also documented product profiles guiding their crop improvement programs and these are highlighted under each program's report.

To boost legume seed production and delivery to smallholder farmers, a multi-pronged strategy was used, consisting of building partnerships between farmers, seed companies, governmental organizations and extension workers; training seed producers, marketers in technology and best practices through participatory varietal selection, on-farm demonstrations and mobile app-based advisories. While there were initially less than a million farmers growing improved varieties of the target legumes in the target countries, by the end of the project in 2019, there were nearly 22 times as many. The TL projects helped CGIAR and their NARS partners to develop and release a total of 304 improved varieties of targeted legume crops, produce 397,050 t of certified seeds of the legume crops in the target geographies and train 52 new scientists. Of the certified/ Quality Declared Seeds (QDS) /TLS produced during the four years of TL III, 11% was distributed in small packs to enhance wider and affordable access to seed of improved legume varieties, especially by resource-poor women famers. A total of 1660 seed enterprises (seed companies, farmer organizations, farmers groups, public seed enterprises, and individual seed entrepreneurs) were engaged in seed production/marketing across legume crops in the target countries.

The use of multiple stakeholders to produce and deliver EGS, certified and quality declared seed has been a successful approach. For example, in addition to the over 400 farmer groups involved in groundnut seed production in Tanzania, private seed companies have started showing interest in groundnut seed seep production. Several negotiations and interventions are ongoing to strengthen the connection between the various categories of seed producers so that they leverage one another's strengths to deliver various seed classes. Furthermore, the established and strengthened multi-stakeholders platforms (MSPs) have been instrumental to produce and avail seed to smallholder producers at affordable cost thereby stimulating demand. The strategic partnerships established under the project are key in sustaining production of both EGS and certified seed. Recently, ICRISAT has initiated a seed revolving fund initiative with seed companies in Tanzania to build on the momentum gained so far through enhanced private seed companies' investments in all classes of seed. This also involve putting in place incentives for the youth to attract them to the sustainable seed production and delivery systems. In Nigeria, seed companies can now obtain license from the National Agricultural Seed Council (NASC) to produce their own foundation seed for use. Some private seed companies have also obtained certificates from the NASC to produce and market foundation seed. Two public institutions with revolving funds (autonomous financial capability) produce EGS and supply to seed companies. Most of the seed companies have been linked to the public institutions.

The engagement of the private sector companies to enhance the availability and accessibility of seed and ultimately to enhance sustainability of seed supply is improving bean seed production and supply. This is being done in various ways

1. NARS are contracting private sector to produce breeders seed (TARI–Selian). This brings efficiency and creates business opportunity for private sector
2. Some private seed companies are producing basic seed after getting breeder seed from NARS and continue with the rest of the seed supply chain

3. Seed being a derived demand, we have embarked on the implementation of grain demand responsive seed systems, which is based on grain market pool through the bean corridors and working with grain aggregators.
4. The grain demand responsive seed systems help us to reduce the number of varieties to multiply and also the products to develop
5. Support both grain aggregators and seed producers to develop a joint seed road map, which provides the linkages among the two.
6. Licensing varieties have been initiated – already CIAT has signed license agreement with 4 companies and some have started the commercialization and two more have made request.
7. Continuous skills, knowledge enhancement, interactions between private, and public sector breeding and seed systems will help private to overcome their shyness in engaging legume seed.

Many farmers and other legume value chain actors have been reached through demos and other awareness creation activities (field days, seed/agricultural exhibitions/shows, radio shows etc.). For example, a significant increase in adoption levels of groundnut has been reported in Nigeria's project intervention areas (about 44%) and most of the old varieties in Tier 1 countries (Nigeria and Tanzania) where the surveys have been conducted are being replaced fast with project promoted new varieties. A forensic audit to establish which approaches could be attributed to increased uptake of the promoted technologies is necessary through an external survey by an impartial team. Private sector companies interests are increasing in legume seed business e.g. common beans and groundnuts in Tanzania and chickpea in Ethiopia and India. Farmers are interested in buying seed once they know the varieties or heard about it. Investments in demand creation is an imperative. For instance, in Tanzania in 2015, we did not have a single company engaged in bean seeds, now we have six seed companies. Similarly, there are 4 companies currently multiplying groundnut seed and more are showing interest. The seed company's entry into bean seed production and commercialization came after several joint demand creations initiatives using multimedia approach (agro –dealers led demos supported by local field days and supported by radio talks and WhatsApp groups messages) about quality seed and new varieties. More important is availability of the right varieties that are highly marketable to incentivize the farmers. In Uganda, there are twelve seed companies engaged in bean seed. We are currently testing new models to increase farmer purchase and use of seed of improved varieties through the existing commodity corridors whereby linkages are make among seed companies, QDS producers, grain farmers and the grain off-takers for a clear market outlets and market incentives; this is already being built in Tanzania for groundnut and beans.

The Tropical Legumes Projects did not do well in gathering and archiving PVS and demonstration data at a central database. Most of demos and PVFS have been focused on both yield/productivity and farmers overall ranking- generally farmers provide their assessment criteria beyond yield e.g. marketability, maturity period, disease and pest tolerance. The PVFS results were used for variety release and will continue to provide useful feedback to the product profile. Based on lessons learnt in TL projects, under the AVISA project, the project partners are collecting basic data on all demos and PVS that will be conducted. Such basic data include yield, names of varieties including the target ruling variety to be replaced, key traits of these included varieties etc. In all AVISA meetings, strong emphasis has been put on the demo and PVS data. Due to the slow progress of data collection on demos and PVS, we have made provision on ICRISAT e-data collection platform (MEASURE) to monitor the effectiveness of data collection on those demos and PVS.

Project outputs were disseminated through a Special Issue (https://onlinelibrary.wiley.com/doi/abs/10.1111/pbr.12632) in the journal Plant Breeding with 10 peer-reviewed articles highlighting 12 years (2007–2019) of research, achievements, lessons learned, challenges and gaps in discovery-to-delivery research in Tropical Legumes. Information on the project activities was regularly shared through many social media channels including: https://twitter.com/tropicallegumes; https://www.facebook.com/tropicallegumesIII/; https://www.linkedin.com/groups/7039014/?msgConversationId=6320815379241410560&msgOverlay=true; https://www.youtube.com/channel/UCFi3qGwZoYX5jJkvuvH_o7w. https://www.flickr.com/photos/tropicallegumes/. The project also developed a digital seed roadmap and catalogue: http://seedsystems.icrisat.org as well as a digital MLE framework: http://measure.icrisat.org.

A critical analysis of the Tropical Legumes projects: The Big Picture and Where We Need to Go Next

The Tropical Legumes Projects aimed to increase the productivity (yield per unit area) and production (total availability) of six grain legumes – groundnut, cowpea, bean, chickpea, pigeonpea and soybean in Phases 1 and 2. The project had emphasis in developing, testing and promoting improved crop cultivars (and associated crop management practices) to enhance legume productivity and production in the drought-prone areas of target regions and countries. In this connection, the partners put concerted efforts in developing cultivars tolerant to drought and the major pests and diseases using plant-breeding techniques such as marker-assisted selection supported by The Tropical Legumes I and other related projects. A major thrust was to develop sustainable seed production and delivery systems in project countries that enhance access to improved legume varieties by resource-poor farmers. Social science research was positioned to analyze and provide advice concerning the social and cultural environments that influence the sustainable adoption and spread of promising varieties, technologies and innovations, and the scaling-up and scaling-out work done amongst farm communities. It was also the intention of the project that the social science inputs support research developments in breeding through a feedback process, policy dialogue, and by identifying lessons learnt for technology dissemination. In order to ensure the sustainability of legume breeding efforts in the project countries, capacity building and infrastructure development of national programs in breeding and seed delivery systems were major goals.

The TL-III project built directly upon the outputs and momentum of TL-II, but was strategically focusing on fewer crops (did not include soybean and pigeonpea) and fewer geographies (seven African focus geographies and the Indian State of Uttar Pradesh), integrating the genomic resources developed in the TL-I with the applied breeding and seed delivery initiatives of TL-II. Three complementary research and delivery pillars were used to deliver TLIII outcomes: 1) Support for the development and release of farmer-preferred varieties in the priority legume crop x geography; 2) Strengthening of the legume breeding capacity of the partner CGIAR centers (ICRISAT, IITA and CIAT) African stations (Nigeria, Mali, Uganda, Malawi), and national partners through a formal and structured assessment (Breeding Program Assessment Tool or BPAT) and improvement process, to enhance their capacity to deliver improved cultivars beyond the timeframe of the project; and 3) Establishing of sustainable seed delivery systems that service the needs of small-holders, especially underserved women farmers in the African partner geographies.

The structured BPAT was employed to help guide the assessment and implementation process designed to lead to improved operational protocols, improved experimental design and the use of new analytical methods and tools, including the adoption of 'Breeding Management System' (BMS). The overall goal was to encourage breeders to expand their breeding pipelines by evaluating more materials with greater precision and less error. Some of the indicators of genetic gains set out during TLIII included number of nursery plots managed per breeder (should be gradually increasing), number of trial plots managed per breeder at each testing stage (should be gradually increasing), proportion of trials planted that generate data used in making selections for the next season, cost per nursery and trial plot (should be gradually decreasing), heritability of yield and other agronomic characters improving, and mean yield advantage of newer materials higher than checks. The BPAT exercise intended to identify and implement program improvement elements that substantially impact genetic gain but that are also doable and low cost and prioritize these for early action. For example, reducing experimental error included field rotation practices, land preparation practices/levelling, experimental designs and statistical analysis, seed quality issues and well as plot harvesting and sample handling practices.

Initial efforts in product profile development, program design, trial quality execution and data information management and analyses started during the TLIII. These became the building blocks for proposing a data-driven and gender- and nutrition-informed Product Profiles to be developed within each breeding program under AVISA. In AVISA, production and socio-economic environments will be characterized and market intelligence collected from men and women farmers, consumers, millers, marketers, seed dealers and health/nutrition specialists to routinely adjust and support product profile design. Sophisticated market, nutrition and gender-informed product profiles will be developed to prioritize traits and direct each breeding program. A feedback system for monitoring and updating the product profiles will be implemented to ensure that breeding programs continue to meet the needs of women and men smallholders and have suites of traits with the greatest potential impact on livelihoods within a given production context. Production areas, foresight analysis will be conducted to estimate demand and the geographical distribution of future grain and seed demand, market requirements and socio-economic environments will be characterized to help define and refine product profiles. This way, the social sciences will be better integrated with the product development process, making the final products more acceptable to value chain stakeholders.

The genetic gains equation ($R_t = \frac{irs_A}{y}$) has become increasingly a focus of public breeding efforts, with emphasis made on the time taken per cycle. This is the basis of establishing high throughput Rapid Generation Turnover (RGT) platforms, including upgrading regular glasshouses fitted with supplementary lighting and air conditioning to maintain temperature and humidity. This highly efficient rapid cycling facility has the potential to enhance the number of generations produced per year. Careful parent selection based on available phenotyping data, genotyping data and if possible, simulation is still a prerequisite for genetic gains enhancement. Parents should have maximum number of favorable alleles for traits required for product profile. Implementing early generation selection using marker assisted tools as espoused in the HTPG project would help to reduce number of lines carried forward in SSD. While making emphasis of improving the efficiency and effectiveness of the breeding process, it is important to take stock of available markers and if need be design new ones through fast-track mapping approaches. Success of the breeding programs depend on the availability and accuracy of phenotype, genotype, and pedigree data that could and should be availed through relational databases and centralized services like HTPG, GOBii, EiB, etc.

In recent years, due to significant advances in plant genomics and as a result of investment from TL projects and several other related projects funded by international agencies, large scale genomic resources including genome assemblies, re-sequencing, markers for different traits and a range of genotyping platforms have been developed in these legume crops. In almost all crops several improved varieties developed through molecular breeding have been released in several countries. Some CGIAR locations in Africa and NARS legume-breeding programs have institutionalized the use of genomic resources and many breeders require mentoring to interpret genotyping data and make selection decisions. Thus in order to fully leverage these genomic resources and technology toward applied goals, substantial integration of genomic techniques in improving the genetics in seeds with the process of improving operational efficiency is needed. To accelerate genetic gains, institutionalizing marker-assisted breeding will help with expanding the number of lines to be evaluated and precision in selection particularly of difficult traits such as drought. With the availability of HTPG and several other platforms, it is now possible to outsource genotyping, it is important to integrate new approaches like early generation screening, marker-assisted selection, as well as genomic selection (by undertaking phenotyping of populations in target environments) in breeding programs with more emphasis on continuous population improvement (and not just product development).

Inadequate seed production systems and the lack of access to seed by distant smallholder producers are particular bottlenecks to the adoption of improved varieties. Despite demand, the private-sector seed industry has been reluctant to invest heavily in grain legumes due to the lower margins and lower and more erratic sales volumes (largely because farmers have the option of using saved seed) and other constraints. Institutional and technical innovations to overcome these obstacles have shown promise following the seed system work of the TL-II and seed is beginning to be delivered at scale in some geographies. To get the improved seed of the new varieties to farmers, more than ten seed production and delivery models for selected crops were tested during Phase II of the TL-II. Several models proved highly efficient in supplying smallholders. However, a product advancement process that communicates back to the breeding programs and backed by robust demonstration trial data, to make confident conclusions and recommendations for variety turnover by public and private sector seed enterprises was not in place. Thus, the breeding process in TLIII was process- but not necessarily product- or business-driven. The focus going forward is on the decision-making criteria of markets and advancing a defined selection of products, making breeding business-oriented.

Besides, the Tropical Legumes projects had put significant emphasis on the push end of seed production and supply but less on the pull end. That approach created significant impacts during the project period but is likely to be unsustainable if the profitability of the varieties are not demonstrated to potential commercial investors. AVISA is therefore testing new models of EGS (breeder and foundation) and certified/QDS seed production through demand-led public and private partnerships. This involves fast-tracking variety registration in regional catalogues and regional marketing approval, thereby creating demand for grain and seed in the regional markets. It also involves flexible licensing strategy for public varieties in order to leverage private sector capacity in seed dissemination and fair and equitable partnership between public breeders and selected seed companies. Equitable licensing models are being designed that return royalties to public breeding and provide market signals back to breeders, providing an opportunity to reach farmers at much greater scale and defray part of the operating costs of the public research institutions. Seed companies of sufficient size, capacity and ambition to produce their own foundation seed are being engaged under license and their capacity built to diversify their crop portfolio to include AVISA crops. For example, Premier Seed Company in Nigeria has good field infrastructure and an experienced sorghum breeder, and is in the process of establishing its own foundation seed production capacity

AVISA Seed Systems team is making efforts to replicate the success of seed revolving fund model to address limited production and supply of EGS. The model involves public and private partners at each stage of the seed value chain where breeder seed is produced and supplied by the public breeding institution. Farmer seed producer groups are trained in quality seed production, and contracted by the SRF to produce foundation seeds, at agreed buy-back prices. Individual larger scale farmers could also be contracted to multiply seeds for the SRF, especially if they have irrigation facilities that will guarantee availability even in drought years. It is important for the entrepreneurs to purchase breeder seed instead of the SRF providing seed and deducting from the sales. Foundation seed is then sold to local seed ventures for multiplication into certified seeds. The companies then sell to a larger number of farmers through agro-dealers. Proceeds of the sales realized through the SRF are ploughed back to cover the operational costs such as staff, inspection and certification, warehouse, seed packaging and transport, and this enables the fund to engage more entrepreneurs every year. The success of the SRF model requires strict Standard Operating Procedures to ensure good quality seed and also avoid conflict of interest by staff. Another important requirement is that the proceeds from the sales must "revolve" to enable the unit to make further investments and carry out all the necessary operations in a timely manner. This may involve consultation with Governments to set up financial management structures that provide an easier accountability process. The situation Analysis of what went well and what did not go well during the Tropical Legumes Projects and the ways forward is captured in Annex 2.

Strategic Partnerships with Legume Research and Value Chain Actors

Much of the successes of the Tropical Legumes Projects were collective efforts of key critical partners, collaborators and co-operators. The projects performed more of a guiding and catalytic function towards collective success delivering large collective impacts, and helping sharpen the way the CGIAR and its partners drive agricultural transformation. Modernizing Ethiopian Research on Crop Improvement (MERCI) project, for example supported the breeding program of common bean and chickpea to improve their optimal performance and effectiveness in breeding and generating improved varieties of the crops with important traits. The Feed the Future Climate Resilient Chickpea Innovation Lab emphasized breeding of high-yielding, climate resilient chickpea within the context of user-preferred traits: seed quality and nutrient density, reduced inputs due to climate resilient nitrogen fixation, and biotic stress resistance among them. This was done through collection of wild chickpea accessions, identification and are introduction of newly collected wild alleles into diverse high performing elite cultivars, a pre-breeding process that added significant value into the breeding programs of Ethiopia and India. Similarly, Government of India supported development of markers and deployment of MABC to develop improved varieties for drought tolerance and fusarium wilt resistance in chickpea in India.

The Feed the Future Innovation Lab for Peanut built partnerships between peanut-breeding programs in the US and some of our Tropical Legumes Project focus countries to enhance the capacity of peanut-breeding programs in each country to develop new varieties that increase yields and address the local, national and regional demands. The support to partners included Integration of Peanut Throughput Phenotyping (HTP) for Enhancing Breeding Programs, Leveraging genetic resources to enhance peanut/groundnut breeding in Africa and the US, Incorporating new wild alleles to improve elite West African peanut cultivars, mapping Groundnut Rosette Virus (GRV) resistance for marker-assisted selection, Enhancing the genetic potential of peanut production in West Africa, Use of novel genetic diversity for peanut varietal development in East Africa, Enhancing the genetic potential of peanut production in Eastern and Southern Africa, Developing Aspergillus flavus-resistant peanut using seed coat biochemical markers, Genotypic analysis of peanut germplasm using the Axiom_Arachis2 SNP array, Breeder seed production and assessment of breeding programs' capacity-building needs in targeted African countries, Adoption and implementation of digital data management system and analytical pipeline by groundnut breeding programs in Malawi, Mozambique and Zambia, Breeding and enhancement of tolerance to water deficit, resistance to leaf spot and improved oil composition in peanut. Similarly, with support from several other donors like Government of India and MARS-Wrigley (USA), ICRISAT Hq developed and contributed to development of large scale genomic resources including genome assemblies, markers associated with several traits and a range of marker genotyping platforms. TL and above mentioned projects supported deployment of MABC to develop foliar disease resistant and high-oleic acid lines in groundnut in India. Some of these materials have also been transferred in several West African countries like Ghana, Mali, Nigeria for trait evaluation.

The Feed the Future Innovation Lab for Legume Systems Research fostered dynamic, profitable and environmentally sustainable approaches that contribute to resilience, productivity and better nutrition and economic opportunities for legume farmers. Feed the Future Innovation Lab for Climate Resilient Beans project integrated phenomics, genomics, and accelerated breeding programs to produce more resilient, productive bean varieties for smallholder farmers. It integrated cross-disciplinary research, from targeted trait selection and marker-assisted breeding to dissemination technologies, to develop and release new locally adapted bean varieties with greater tolerance to drought and heat stress, for rural communities in Eastern and Southern Africa, linking with PABRA networks. The Climate-Resilient Cowpea Innovation Lab developed and applied advanced genomic tools to cowpea breeding to increase yield, drought tolerance and fungal resistance in cowpea, working very closely with our partners from IITA and Burkina Faso.

The Program for Africa's Seed Systems (PASS) of the Alliance for a Green Revolution in Africa (AGRA) helped by supporting education for the Next Generation of breeders in Africa, through African Center for Crop Improvement (ACCI) and West African Center for Crop Improvement (WACCI). Some of the breeders trained through this process became focal persons for collaborating institutions in the tropical Legumes Projects, besides receiving research grants from the program for variety development. The report also covers the story of AMWARI Seed company in Ethiopia currently supported by AGRA. AGRA supported tens of other seed companies across Africa, come of whom are currently marketing products of the Tropical Legumes Project, while we are working with others for product portfolio diversification to include our target legumes and cereals under AVISA. Besides financial support from AGRA, some of the seed companies and seed producer groups receive marketing and value chain support from Integrated Seed Sector Development (ISSD). ISSD works to create an enabling environment for innovation and the coexistence of different seed systems, leading to increased access to quality seed.

The Pan-African Bean Research Alliance (PABRA) framework is a consortium of African-owned regional networks, encompassing the Eastern and Central Africa Bean Research Network (ECABREN), the Southern Africa Bean Research Network (SABRN), and the West-Central Africa Bean Research Network, with CIAT and the donors. The three networks have grown out of previous regional networks that were established as early as 1984, and have a membership of 31 national programs that bring together African universities, NGOs, and the private sector as well as government R&D institutions. CIDA-Canada and SDC-Switzerland are currently the major donors of the alliance. Other donors such as McKnight Foundation and the Kirkhouse Trust fund specific components of the program. This network brought together important lessons into the project besides networking the partners for implementation of the Tropical Legumes Projects.

The Tropical Legumes Projects worked with various national partners as indicated in *Annex 3*. On seed production and delivery, the project also collaborated with large Feed the Future Scaling Projects. TL III investment focused on production and marketing of breeder, foundation, and certified seed, while the USAID Scaling project focused on production and marketing of certified seed. USAID Cowpea, groundnut and chickpea Upscaling Projects sourced breeder and foundation seeds from TLIII project. The Scaling project leveraged on existing partnerships of TL projects to produce certified seed of the improved varieties released/recommended during TL II. Irrigation facilities were installed in Ethiopia, Nigeria, Ghana and Mali using TL III funds to produce breeder seed during off-season at the research stations in addition to main season. Nigeria made significant progress in dry season seed production by supporting famers to utilize irrigation facilities across the country.

INTRODUCTION

The TL III project built on the foundations of TL I and TL II Phases I and II. The two projects were funded by the Bill & Melinda Gates Foundation and implemented by ICRISAT alongside IITA and CIAT together with NARS in 15 participating countries. They ran from 2007 to 2015 before another 4-year phase called TL III was conceived and ran from 2015 to 2019. In this report, we reflect on the implementation and accomplishments of TL III with some reflections on its precursor projects. In this context, we structure the report based on the baseline status, interventions and outcomes of the TL III programs.

ICRISAT WCA Groundnut Crop Improvement Program

ICRISAT groundnut-WCA program provided support to NARS groundnut programs in Nigeria (IAR), Mali (IER) Burkina Faso (INERA) and Ghana (SARI). Spillover countries included Chad, Gambia, Togo, DRC, Ivory Coast, Niger and Senegal. Before the start of TL projects in 2007, the program focused on evaluating advanced breeding lines from India and Malawi, with limited crossing using elite lines from the region. There was limited inclusion of the voices of farmers and other stakeholders in variety development and evaluation. The program was using traditional breeding and would share segregating materials with the NARS programs for advancement using pedigree selection. Infrastructure to support breeding and seed production and delivery was also poorly developed. Marker assisted selection and other genomic support tools were not used. Data was collected, curated and archived manually for analysis. The only form of mechanization by the year 2007 was using tractors for land preparation.

With TL projects, the number of advanced breeding lines evaluated increased and stakeholder participatory evaluation (PVS) was integrated in the evaluation process. Overall, this contributed to the release of 31 varieties with ICRISAT pedigree out of the 33 varieties released in the 4 project countries (Burkina Faso, Ghana Mali and Nigeria). By 2009, the program began its breeding activities, and adopting modern breeding tools including a shift to single seed descent (SSD) and including marker assisted selection (MAS). The number of generations per year increased to 2 compared to 1 in 2009. The number of populations developed, varieties evaluated and advanced breeding lines shared with NARS partners also increased as indicated in *Table 1*. The program has not conducted genetic gains study, but these studies are underway and supported by both GLDC and AVISA. ICRISAT-WCA groundnut program conducts single plant selections at 5-10% selection intensity from F5 to F6 single-plant row observational nurseries. The nurseries are evaluated for traits such as yield and yield components including pod numbers, seeds per pod and pod fill. Selected plants are evaluated in preliminary yield trials, then Advanced Variety Trials followed by Regional Variety Trials. That leads to up to 3000 single plant rows on to which more stringent selection pressure has to be applied.

Currently the program has developed 2 product profiles that are guiding its strategy: (1) Short-duration groundnut with drought, aflatoxin and early leaf spot (ELS) tolerance and (2) Medium-duration groundnut with ELS tolerance (Product Concept Notes of GLDC Crops). In terms of mechanization, the program acquired 2 seed counters, 2 seed graders, 1 pod grader, 1 moisture tester, 1 NIRS, 3 single planter decorticators, 1 medium sized decorticator and large capacity decorticator. A screenhouse has also been set up with the support of the TL project. Data collection is now digitized using tablets; BMS is now regularly used for germplasm management, crossing, nurseries and trials; and nursery and germplasm labels are now barcode printed read. NARS capacity has also been strengthened by the ICRISAT WCA groundnut program through formal training and provision of short courses including 5 PhDs, 1 MSc, 24 interns, 43 on-the-job trainees on plant breeding and 62 technical staff trained on BMS. Summary of the status of the project before TL interventions in 2007, specific interventions that were undertaken and resultant outcomes (2007 – 2018) can be accessed in *Table 2*.

Gender integration in the TL project went from just a concept to gender transformation. Recognizing the realities of men and women farmers' differentiated needs, access to technology, opportunities and constraints in legumes farming communities, TL III worked at mainstreaming gender in the project by focusing on and integrating gender in the following ways: Enhancing capacities for gender mainstreaming in country teams; testing gender transformative interventions to close gender gaps in groundnut production; and access to improved groundnut seeds was identified as a major determinant of productivity differentials and a contributing factor to productivity gaps between male and female groundnut farmers. TL III invested in 3 innovative approaches of enhancing the capacities for gender analysis among teams: (1) MSc level interns -- Four-month internship with specific assignments to deliver on gender analysis assignments provide the intern an opportunity to understand gender gaps while advancing a deeper understanding of the current situation and fosters skills and interest of future scientists in gender research; (2) Doctoral training and fellowship -- TL III invested in the training of a doctoral student for increased capacity in gender research and analysis. The fellowship was offered to a female Nigerian student in the groundnut program; (3) Customized training of teams of breeders and social scientists in the NARS from the TL IIII project countries -- TL III collaborated with Gender-responsive Researchers Equipped for Agricultural Transformation (GREAT) to deliver 'intensive training courses for gender-responsive researchers. The training was designed to ensure the strongest possible gender outcomes and gender targets and supporting activities appropriate to the goals and scope of the project were developed. Details of actions taken are covered under country programs.

Nigeria Groundnut Crop Improvement Program

Before TL project in 2007, the Nigeria groundnut program focused its breeding activities on evaluating advanced breeding lines obtained from other sources, mainly ICRISAT. Modern advanced breeding approaches like phenotyping platforms, genomic tools for marker assisted breeding and digital data capturing and handling and management tools were lacking. At the onset of the project in 2007, there were old varieties with an average age of more than 10 years in the Samnut series 1-20. There was limited EGS seed production within the program, with an annual average of about 580 kg of breeder seed. While the variety turnover was more than 8 years, the seed replacement rate averaged more than 10 years. MSPs were non-existent and there was no private sector involvement in production of groundnut seed. Adoption spread of improved groundnut varieties was as low as 8% while adoption intensity was about 34% with an average yield of less than 1 t/ha (0.857 t/ha). There was limited awareness of improved varieties among farmers, with very few women farmers participating in groundnut production due to poor access to primary production resources like land and high quality seed.

TL projects have enabled the program to adopt modern breeding techniques such as SSD and improve the physical infrastructure and human capacity required to deliver on its national mandate. The project's support was guided by the PIP following the Breeding Program Assessment Tool (BPAT) self-assessment report that identified program weaknesses in physical infrastructure and human capacity. In terms of physical infrastructure, TL project supported this program to renovate its irrigation facility, short term storage facility and screenhouse. In 2017, a fully functional aflatoxin detection lab was established for the program with the support of TL III and hybridization methods were redesigned. Human capacity was enhanced through specialized training like on the use of BMS in 2016 and a course on product profile development. Some of these trainings were also supported by the acquisition of accompanying hardware like tablets for digital data collection. Barcode printers and scanners were also purchased with TL III resources, though by the end of TL III in 2018, the program had not started utilizing these equipment fully due to limited human capacity.

The project conducted several awareness creation and promotional activities including demonstration trials, field days, agri-seed fairs/exhibitions/shows, etc. A total of 10,675 such activities were conducted in Nigeria compared to the 10,600 that were targeted by the project. About 915 groundnut demos were conducted (*Table 3*). A total of 7 MSPs were established under Nigeria groundnut program during the first 2 years of TL III project and 7,883 MSP members were trained in seed production and marketing. Further, the Nigeria groundnut program distributed a total of 1,018.7 t of certified groundnut seed to smallholder farmers in small seed packs (SSPs).

For the project to deliver its seed production commitments, multiple stakeholders were engaged in seed production and marketing. For the 4 years of TL III, the project engaged about 123 stakeholders to produce groundnut seed (*Table 4*). A 2016 survey by the Nigerian government revealed that there are about 560 informal farmer groups across the country engaged in seed production. They collaborated with national (IAR) and international (ICRISAT) research institutes to select and test improved varieties and with seed companies to distribute their seeds nationally and regionally through the seed companies' channels. Through the project, the seed producing cooperatives were strengthened and are increasingly being formally recognized as producers of certified seed, making the project impacts sustainable. Jirkur Seed Cooperative Society, for example, operates a network of agro-dealers at village level in Borno State, providing a much-needed service to farmers in a region plagued by Boko Haram. Kamuyu Agribusiness Centre, which established a national research center in the northwest of the country, is actively expanding into neighboring districts via a network of distribution agents and outgrower schemes. It was established in 2010, and was one of the first cooperatives to be officially registered by the National Agricultural Seed Council, which is the national seed certification authority. Initially consisting of 10 members, it has now grown to 200 members. Its production has also increased, from 50 t to nearly 1,000 metric t annually of maize, rice, soybean, cowpea and groundnut seed. Through a network of agro-dealers at the village level, it has progressively increased its market share and is currently the main certified seed distributor in northeastern Nigeria. It is one of the few cooperatives known to have a woman CEO.

As a result of the support from TL projects, the program is currently making 15 crosses per season with an efficient data curation and archiving scheme (BMS). Advanced statistical design & analysis have been adopted. With improvement in physical infrastructure supported by the TL projects, the program has been able to achieve about 3 generations/cycles per year and the number of testing sites increased to about 4 locations covering 3 agroecological zones. A total of 3 product profiles have been successfully developed: (1) Short Duration (SD), high-yielding varieties with resistance to Groundnut Rosette Disease (GRD), ELS and late leaf spot (LLS); (2) medium-maturing dual purposes varieties with resistance to GRD, ELS and LLS; and (3) Medium Duration (MD) dual purpose, high oil content industrial varieties with resistance to GRD, ELS and LLS. The program has also managed to release 6 varieties (*Table 5*). The program received training in genomics and molecular breeding at the Centre of Excellence in Genomics and Systems Biology (CEGSB) at ICRISAT Patancheru (India). The program is yet to conduct any genetic gains study to measure its progress over the years.

Besides contributing to the breeding program's improvement, the project also contributed to production and marketing of certified seed of groundnut. A total of about 9,996.41 t of groundnut comprising of 32.36 t of breeder seed, 103.3 t of foundation seed and 9860.76 t of certified seed were produced. The project started by injecting 20 t of high quality certified seed into the system that accounted for 0.1% of the certified seed need. In the last year of the project, 1,898 t of high quality certified seed was produced, injecting 0.7% of the certified seed need (*Tables 6 - 9*). These quantities are still low and require a change of strategy. Project interventions and associated enabling factors including strategic partnerships led to a significant yield increase of 222.44 kg/ha (391 kg/ha for females and 200.5 kg/ha for males) and associated income increase of US$ 135/ha (US$ 168/ha for females and US$ 93/ha for males).

Mali Groundnut Crop Improvement Program

Before TL projects in 2007, the Mali groundnut program was only evaluating advanced lines from ICRISAT WCA groundnut program without any actual breeding program. The program had no crossing activities. This limited capacity enabled it to achieve 1 generation per year. Rudimentary manual data collection, archiving and analysis methods were used. At the national level, there were only 3 releases and ruling varieties (47-10, 55-437 and JL 24). There were no breeding schemes and variety turnover and replacement rates were very low. Production of breeder seed of improved varieties was less than 100 kg that of foundation seed less than 1 t and that of certified seed less than 10 t.

After undergoing the BPAT self-assessment under TL III, the program embarked on modernizing its breeding activities by establishing a 4-ha irrigation facility to support phenotyping and production of EGS seed. It also developed phenotyping protocols and renovated the cold storage facility that was dysfunctional. This support enabled the program to achieve 3 generations in a year, up from 1 previously. The program was able to conduct 15 crosses in 2015, 21 in 2016, 30 in 2017 and 51 in 2018. Besides, new breeding approaches have been adopted, moving from pedigree to SSD and backcrossing. The program has been able to develop an increasing number of segregating populations because of project support. Trialing sites and the number of materials in the trials have been increasing since the intervention of the project. From a maximum of 10 trialing sites when the project started, the program is now conducting its trials in a minimum of 30 and a maximum of 80 sites. Going forward, this will be affected by the limited funding allocation in AVISA compared to the Tropical Legumes Project. Moreover, there is still a need to address the program improvement plans, including a glasshouse and dedicated lab facility for aflatoxin.

Apart from physical infrastructure, it was clear from the BPAT that there was need for enhanced human capacity in the program. With the support of TL III project, there were short- and long-term trainings to enhance capacity. Short-term trainings were conducted on the use of handheld devices to collect data and the use of BMS in the program. The project also supported the program to acquire barcoding machine and all the data is now collected using these handheld gadgets and curated in BMS. The project supported training of program staff on product profile development; as a result, 2 product profiles have been developed: (i) Short-duration and climate resilient varieties with resistance to foliar fungal and virus diseases for oil, food and dual purposes, (ii) Medium - duration varieties with resistance to foliar fungal and soil borne diseases for oil, food and confectionery, and dual purposes. The program also received training in genomics and molecular breeding at CEGSB- ICRISAT Patancheru (India). The program is yet to conduct any genetic gains study to measure its progress over the years.

Special training was conducted for program staff on aflatoxin trialing and quantification and installation of aflatoxin phenotyping platform within the program. With the support of the project, the program has been able to release nearly 20 improved high-yielding varieties with resistance to various biotic and tolerance to abiotic stress factors (*Table 5*) and production of breeder and foundation seed has been increasing due to robust interventions like a renovated irrigation facility that allowed off-season production of EGS and the involvement of stakeholders in the production and marketing of groundnut seed in Mali (*Table 10*). On average, about 61 different stakeholders were involved in production and marketing of seed in Mali.

The project also supported the Mali groundnut program in undertaking a robust campaign of creating more awareness of improved varieties. For the 4 years of TL III, a total of 4,108 awareness creation and promotional activities were undertaken (*Table 11*). The program used field day demonstrations, mass media (radio/TV), flyers, agri-seed fairs/shows/exhibitions and FPVS to create awareness and promote new varieties. The program also established 6 MSPs and trained about 3,095 members on groundnut seed production and marketing in Mali.

Finally, with these innovative approaches to seed production and delivery systems, a total of 4,817.86 t of improved groundnut seed was produced in Mali. This comprised of 40.58 t of breeder seed, 187.94 t of foundation seed and 4,589.35 t of certified seed. Further, a total of 1,325 t of certified seed was distributed to smallholder groundnut producers in Mali in the form of SSPs. A closer scrutiny of the seed production trends shows a general increase in the amount produced over the years for each seed class (*Tables 6 - 9*). In the initial year, the project through its partners injected 0.1% of certified seed requirement, which increased to 4.3% in Mali.

Burkina Faso Groundnut Crop Improvement Program

Before the TL project in 2007, the Burkina Faso groundnut program was not undertaking any crossing work. Physical infrastructure and human capacity to support breeding and seed production and delivery were poor. Traditional breeding methods were in place with limited digitization of data collection and analysis. The concept of product profiles was absent. Adoption levels of improved varieties and general awareness among the target communities was low leading to low productivity (500 – 700 kg/ha) and production of groundnut in the country. There were only 9 groundnut varieties on the shelf with an average age of more than 30 years. Production of improved seed was also limited by small amounts of early generation seed that was expensive. With seed delivery systems being informal, there was limited access and adoption by smallholder farmers.

The TL project aimed at modernizing the program by improving physical infrastructure and human capacity. First, with funding from the project, the drip irrigation facility was installed, a green house built, and trial plots fenced off to prevent destruction of trial materials by stray animals. Besides these, the project supported the acquisition of 3 tablets, a barcode reader and printer for digital data collection and trained its 2 technicians on BMS and 1 on molecular markers. Program staff received training on product profile development. The program also received training in genomics and molecular breeding and also in touch with staff at the CEGSB, ICRISAT Patancheru (India) for integrating genomic tools in the breeding process in the coming years.

The program was supported by TL projects to increase awareness of farmers and other stakeholders about improved groundnut varieties through interventions like demonstrations, field days, agri-seed fairs/exhibitions, etc. In the course of TL III, 4,180 awareness creation and promotional activities were conducted by the Burkina Faso groundnut program (*Table 12*). A total of 239 groundnut demos were conducted under TL III.

Besides creating awareness and popularizing new groundnut varieties, the project also established MSPs that were used to train groundnut value chain actors in seed production and marketing. These platforms established during TL III focused on high participation of women and youth because this is the population cohort that is mainly involved in production and marketing of target legumes. By the end of TL III in 2018, 9 MSPs had been established under the Burkina Faso groundnut program, through which over 6,300 members were trained in groundnut production and marketing. To popularize improved groundnut varieties and reach smallholder farmers at affordable cost, the project distributed 134 t of groundnut seed in small seed packs.

To produce enough seed to meet the program targets, the project supported the program's use of different seed value chain stakeholders to produce and market improved groundnut seed. ICRISAT and INERA were responsible for breeder seed production while other stakeholders were engaged to produce and market foundation and certified seed (*Table 13*). On average, about 144 different stakeholders, including individual seed producers (116), farmer organizations/groups (21) and private seed companies (4) were used to produce different classes of groundnut seed annually in Burkina Faso. Women were trained in community seed production at low cost so that they could have access to improved seeds. The training consisted of basic agronomic knowledge such as land choice, variety selection, time of planting, spacing, etc. Five women organizations that are part of the innovation platform (IP) ended up as five women community seed producers, serving others.

The project collaborated with umbrella organizations such as UNPSB in Burkina Faso to access seed-producing cooperatives. These organizations defend the interests of seed-producing cooperatives at the national level, provide technical services or machinery to members to ensure that quality seeds are produced and distributed nationally. The seed-producing cooperatives follow the model where foundation seeds are produced by the national research institute (INERA) and cooperatives in turn produce certified seeds from them. For instance, Co-opérative Agricole de Niassan and Co-opérative Agricole de Bama works with ICRISAT on variety testing and participatory variety selection and produce foundation seed for INERA's Seed Unit. Co-opérative Agricole de Bama sells its seed at the local level directly to farmers and works at the national level with seed company NAFASO, which also exports to other countries in the region. Co-opérative Agricole de Bama in Burkina Faso has 200 seed producers operating in irrigated land, which means it can produce seeds in the rainy season and the dry season. It produces commercial seed as well as foundation seed for INERA and NAFASO. In cooperation with its partners, it trains 10-15 new seed producers annually and provides capacity building services to existing growers. Union des Groupements Pour la Commercialisation de Produits Agricole/ Boucle du Mouhoun (UGCPA/BM) has 169 farmer groups from 15 cooperatives with land size ranging from <5 ha to >100 ha per farmer per crop. Therefore, the best entry point for a sustainable seed system of legumes in Burkina is this public-private partnership involving research centers supplying breeder seed and contracting cooperative unions for foundation seed production which also link up with the private seed companies for contracted certified seed production and commercialization.

With these interventions targeted at modernizing the groundnut breeding program and improving the seed production and delivery system, breeding activities were restarted in 2016 with an average of 2 generations per year and 126 crosses per year. The current focus of crosses is on 4 traits: (1) short-duration lines with moderate levels of resistance to foliar diseases (rust, ELS and LLS); (2) short-duration breeding lines tolerant to aflatoxin contamination; (3) drought-tolerant breeding lines; and (4) medium duration breeding lines with high level of resistance to foliar diseases (rust, ELS and LLS). The program is also currently screening for drought and aflatoxin. Laboratory facilities are available for aflatoxin analysis and quantification because of project support. The program has adopted a product profiles approach to guide its breeding, and is currently focusing on two: (i) Short-duration and climate-resilient varieties with resistance to foliar fungal and virus diseases for oil, food and dual purposes; and (ii) Medium-duration varieties with resistance to foliar fungal and soilborne diseases for oil, food and confectionery, and dual purposes. Testing sites have also increased to 11 from the initial one on-station site. From 9 varieties on the shelf in 2007, the program has managed to release 7 new varieties with the support of the TL project (*Table 5*). Despite these milestones, the program does not have a cold room to store large quantities of seed and the existing glasshouse needs repair. These are the focus of the new project AVISA. However, AVISA funding allocation is too limited to cover the cost of the required improvements and operations. The program is yet to conduct any genetic gains study to measure its progress over the years.

Impressive results have been observed in the seed production and delivery system. Production of breeder seed has consistently been improving since TL III's inception in 2015. The amount of breeder seed produced increased from about 3.5 t in 2015, 5.6 t in 2016, 6.1 t in 2017 to 10.9 t in 2018 (*Tables 6- 9*). The total amount of groundnut breeder seed produced through the support of TL III was about 36 t. Foundation and certified seed production too saw a gradual increase from Year 1 to Year 4. A total of 1,036 t of foundation seed was produced. On the other hand, 11,474 t of certified seed was produced over four years of the project in Burkina Faso.

With 11,474 t of certified groundnut seed produced in Burkina Faso in the last 4 years of TL III, the seed was enough to plant about 114,740 ha of groundnut, producing about 91,258 t of groundnut worth US$ 26.32 million. This implies that the project reached about 573,702 smallholder groundnut farmers in Burkina Faso during TL III. However, going back to the start of TL projects in 2007, the project managed to produce about 12,087 t of certified seed by the end of TL III in 2018 (*Tables 6-9*). Using a standard average seeding rate of about 0.1 t/ha, the 12,087 t of seed was planted on about 120,870 ha producing 121,837 t of groundnut worth US$ 60.6 million. With 120,870 ha under smallholder groundnut farmers in the country, the project managed to reach about 604,352 smallholder farm households[1]. In the initial year, the project through its partners injected 0.2% of certified seed requirement, while in the last year, the seed produced could cover 6.4% of total area under groundnut in Burkina.

Ghana Groundnut Crop Improvement Program

The Ghana groundnut program joined the TL project in 2012. The program had halted groundnut breeding activities in 2008, prior to which groundnut productivity was less than 1 t/ha, and the program was using conventional breeding approaches and methods (manual data collection, traditional designs and basic analysis). Seed production and delivery systems were informal with limited EGS and certified seed production. There were less actors in seed production and delivery. The level of farmer awareness of improved varieties was very low, no PVS in variety evaluation and most farmers were recycling their own saved grain as seed.

On joining the project, the program's breeding activities were revived with more focus on evaluating advanced breeding lines obtained from ICRISAT and other partners. Under TL III project, the program underwent BPAT self-assessment and developed PIPs to guide it in rejuvenating its breeding activities and delivering on its national mandate. Key among the BPAT recommendations that were implemented under the PIPs was physical infrastructure and human capacity improvement. Among the key infrastructure improved with the support of the project was the irrigation facility (2017) and securing the experimental plots with a modern fence to keep off stray animals. The human capacity of the groundnut program has been enhanced by the TL III project through elaborate trainings on BMS, product profile development and institutionalization of the digital seed roadmaps. The program also adopted modern breeding techniques like SSD in population segregation. The program received training in genomics and molecular breeding at CEGSB-ICRISAT, India. The program is ready to integrate genomic tools (QTL discovery, development and use of molecular markers) and they are already testing molecular breeding material developed at ICRISAT Hq, Patancheru. High throughput phenotyping work is not being undertaken by the program due to limited financial resources. On the other hand, TL III has enabled the project to adopt modern data collection tools like android-based tablets and barcoding device and designing experiments using the Field Trial Manager in the BMS with data being curated in the same system. Experimental plots also have been fitted with barcoded labels. The program is yet to conduct any genetic gains study to measure its progress over the years. In terms of selection intensity, the program has selected the top 5-10% in the last three years. The genotypes that fall within this group after ranking are selected. The ranking is based on an index comprising pod yield (60%), haulm yield (20%), tolerance to early leaf spot (10%) and tolerance to late leaf spots (10%).

To increase technology awareness and stimulate adoption of improved groundnut varieties in Ghana, TL III supported the program in conducting several awareness creation and promotional activities including demos, field days FPVS, flyers and establishment of MSPs (*Table 14*). A total of about 10,520 awareness and promotional activities were undertaken. Specifically, the project supported 325 demos, 387 field days and 84 FPVS over the 4 years of TL III. The groundnut program also established 5 MSPs in the first and second years of TL III that were used to train 10,000 stakeholders in seed production and marketing throughout the project's lifetime. Over the TL III project period, 46 t of seed was sold through SSPs to reach last mile farmers, to popularize new groundnut varieties in Ghana and as a way of enabling smallholder groundnut farmers to afford improved seed.

Though breeder seed production remained the preserve of SARI and ICRISAT, the groundnut program in SARI adopted the innovative model of involving many seed production and marketing value chain actors for foundation and certified groundnut seed production. On average, 7 different seed production and marketing value chain actors (individual seed entrepreneurs, farmer groups and private seed companies) were involved in the production of EGS and certified groundnut seed in Ghana (*Table 15*). The program was in discussion with the Seed Producers Association of Ghana (SEEDPAG) that was incorporated in 2009 to provide a forum for interaction and information exchange among registered seed producers in the country. After a period of working as an outgrower, some of the members set up their own small businesses and join the National Seed Trade Association of Ghana (NASTAG) as individual companies. SARI collaborates with the Grains and Legumes Development Board of the Ministry of Food and Agriculture to supply foundation seed to members of NASTAG. SARI farmers such as Asawaba Farms produce seeds and hand them over for storage and awareness creation to Seed Inspection Unit at a fee. This model is unique, as farmers trust the Seed Inspection Unit as a source of high quality seed.

By 2016 (Year 2 of TL III project), the program was making about 12 crosses per year and moved on to 16 crosses in 2017. By the end of TL III project in 2018, 20 crosses were being made per year. With the irrigation facility up and running, the program is now able to achieve 2 generations per year. The number of trialing sites also increased from 3 locations in 2016 to 8 by 2018. In 2015, SARI participated in the first ever international trial with TL III support. The program has managed to develop and align two product profiles to guide breeding activities: (1) Short-duration and climate-resilient varieties with resistance to foliar fungal and virus diseases for oil, food and dual purposes; and (2) Medium-duration varieties with resistance to foliar fungal and soilborne diseases for oil, food and confectionery, and dual purposes. In 2018, the program released two varieties, Sarinut 1 and Sarinut 2 (*Table 5*).

With multiple stakeholders involved in seed production, a total of about 449.7 t of groundnut seed was produced in Ghana under TL III. Out of this, about 20.9 t was breeder seed, 61.5 t foundation seed and 367.3 t certified seed (*Table 6-9*). Village Savings and Loans Association (VSLA) across five communities in Northern Ghana were established; women groups were trained and supported to save money and produce QDS of improved varieties of groundnut. The VSLA members were introduced to pipeline groundnut varieties (GAF 1665, GAF 1723 and ICGV-IS 08837). http://gldc.cgiar.org/empowering-women-farmers-through-village-savings-and-loans-associations-vsla-in-northern-ghana/

By the end of the project, the intervention strategy achieved the following:

- 40% increase in the financial capital base of the group members, through weekly savings for a period of one year.
- The groups produced 5 t of QDS of NkatieSARI from 25 acres across project communities, and generated a total revenue of GH¢ 15,000 (US$ 2,742) from the sale of these seeds.
- The groups cultivated 10 acres of QDS of NkatieSARI for the 2019 cropping season.
- Comparing the VSLA with non-VSLA communities, the VSLA members were assessed to have:
    - Improved access to credit for crop production and expanding off-farm related businesses.
    - Improved access to arable lands for crop production and

[1] Cumulative since 2007 when TL project commenced

- Improved women involvement in household decision-making.

ICRISAT ESA Groundnut Crop Improvement Program

Before the TL project in 2007, the ICRISAT ESA groundnut breeding program was using conventional breeding methods and making 50-100 crosses per year. There was no marker-assisted selection and the infrastructure was very limiting to the extent that the program could only manage about 2 generations in a year. Data collection, curation and archiving was also rudimentary. Breeding focus was on input traits like drought and the diversity in the gene bank was limited; hence most varieties shared a common parentage. At this initial stage, the program had a mixture of gene bank accessions and breeding materials. For example, it had only 9 donor sources for different traits. About 15 varieties had been released in the region before TL projects and old varieties were ruling. Generally, the groundnut programs in the region were weak. There were no MSPs and production of seed was limited to an average of about 200 t annually for all seed classes (EGS and certified). The seed delivery systems were largely informal.

Key intervention areas for TL projects in ICRISAT's ESA groundnut program included improvement in infrastructure, building of capacity and reorienting the breeding focus. The project supported the program in modernizing its breeding activities (human resource training, automated system, targeting sites and TPE) and realigning its breeding strategy to key product profiles that were developed in the region. These product profiles are built on priority traits like low aflatoxin contamination, nutrient dense products and amenable varieties for the food processing industry. The project supported the program to increase its gene bank accessions from 9 donor sources to 18 and it is working on developing new sources/parents. For instance, the program characterized a number of materials and identified the best sources for different traits including chromosome segment substitution lines (CSSL) Fleur 11 x (*A. ipaenesis* x *A. duranensis*) from TL I. The old sources of resistance to rust were confined to ICGVs 94114 and 95342. During the project, four new sources (ICGV 01276, ICGV 02286, ICG 11426 and ICG 02194) were validated, thereby expanding the genetic base. With the same token, the resistance base of ELS was expanded from ICGV-SMs 95741 and 93555 to ICGs 405, 6022, 14466, 6057, 12509 and 9449) and that of GRD from RG 1, ICG 12991, ICGV-SMs 90704, 91706 and 94586 to include ICGs 14705, 13099, 9449, 6888, 15405, ICGV-SMs 08503, 01731 and 01514.

The program is yet to conduct any genetic gains study to measure its progress over the years. Currently, era studies are ongoing but further guidance from EIB is sought. Preliminary assessment of genetic gains pending comprehensive systematic studies that are underway show appreciable progress. This was particularly during the TL projects, and the preliminary results show a genetic gain of 0.45-0.6/year for Valencia/Spanish and 0.86-0.9/year for the Virginia. The selection intensity for Valencia/Spanish is 10-15% whereas for Virginia is 20%, and the difference is attributed to differential reaction to the groundnut rosette disease (GRD) among the two groups i.e. Virginia is more resistance and Spanish/Valencia are more susceptible. The gain can be attributed to reduction in breeding cycle (Valencia/Spanish-2; Virginia-1.5) and use of elite lines in the crossing programme translating to accuracy.

For the Groundnut program at HQ, breeding progress has been measured by comparing finished lines, estimated during 1996-2010 for the ICRISAT bred groundnut varieties. An annual pod yield increase of 6-53 kg/ha, equivalent to 0.22 to 2.4 % (average 0.75%) was recorded in Spanish Bunch varieties. There is scope to improve hundred seed weight and shelling outturn, in future to further enhance pod yield. The team at the HQ has completed 4 seasons era trails across different groups of GN, data of 4th season is in progress and by the first quarter of 2020 a comprehensive report will be ready.

In the last 6 years, the ICRISAT ESA groundnut program's capacity to handle trials and data has improved significantly due to TL investment. These included digitized data collection, curation and archiving, both internally and for the participating NARS programs in the region. The capacity to adopt BMS greatly improved. The program also conducted gender gap analysis in select project countries in the region in close collaboration with CRP-GLDC.

TL investments enabled the program to adopt modern breeding techniques that include marker-assisted selection that has enabled identification of quantitative trait loci (QTLs) for rust, oleic acid and late leaf spot that are being validated at HTPG Platform at Intertek, Sweden. The average annual generations achieved within the program have increased from 1 to about 2-3 currently while crosses have been ramped up to more than 300 compared to 50 – 100 at the beginning of the project in 2007. Due to improved resource support from TL projects, the program has characterized its testing sites and target population of environments (TPE) and also increased the number of partners in ESA to expand and expedite material testing and variety release (*Figure 1*). Sharing of advanced materials across the NARS program in the region has increased under TL projects. The number of varieties being released has increased in different project countries. For instance, about 25 varieties have been released in 4 countries since 2014. MSPs have been established in Uganda and Tanzania and a new approach to seed production and delivery adopted across the region because of TL projects since 2007 e.g. the establishment of a seed revolving fund and involvement of many stakeholders in seed production and delivery. The ICRISAT ESA groundnut program conducted several gender mainstreaming workshops intended to close identified gender gaps in groundnut value chains. The program now operates under the guidance of predetermined product profiles (Product Concept Notes of GLDC Crops).

Tanzania Groundnut Crop Improvement Program

Before the TL project in 2007, the Tanzania groundnut program was using traditional breeding methods (manual data collection, curation and archiving). There were no crosses made at this point and the program was receiving and evaluating on average about 11 lines from ICRISAT. The number of released varieties was 6 though adoption was dominated by 4 ruling varieties with an average age of more than 15 years. The program has an irrigation system that is used for phenotyping trials, and breeder seed production during the off-season. On average, the program was producing about 2.6 t of breeder seed annually, 21.4 t of foundation seed and 205 t of certified seed. Yield of improved varieties ranged between 1 – 1.5 t/ha and female farmers faced constraints in accessing productive resources thereby widening the gender yield gap in favor of male farmers.

The project has supported the Tanzania groundnut program in modernizing its breeding program through improvement of both physical infrastructure and human capacity development. The program received training in genomics and molecular breeding at CEGSB- ICRISAT Patancheru (India). Most of the interventions were guided by the PIP developed from the self-assessment BPAT report that was supported by TL III. The project supported the renovation of the storage facility and bought a fridge. For increased efficiency, there is need to upgrade the renovated storage facility to a cold storage. The digitization and modernization of data collection in the program kicked off in 2015 under TL III when the program received tablets, a barcode reader and printer. Over time, the program has been receiving training on the use of BMS in planning, crossing and nursery management. Currently all the data from Preliminary Groundnut Variety Trials (PGVT), Advanced Groundnut Variety Trials (AGVT) National Performance Trials (NPT), Participatory Variety Selection (PVS) and crosses are in the BMS. The groundnut program staff have also received training in product profile development. To date, the program does not have a glasshouse, and though it has 4 oxen-driven planters, they are not in regular operation due to limited human capacity. The Tanzanian groundnut-breeding program has not conducted genetic gain studies, but these are planned in AVISA. The selection intensity is at 10% from F5 onwards.

Under TL III, the program was supported to establish MSPs that have been used to train stakeholders in seed production and marketing of improved groundnut seeds. A total of 10 MSPs were established in Tanzania in the first 3 years of TL III, and 5,752 of its members trained in good groundnut production and marketing practices. TL III supported the program in conducting 7,052 improved groundnut awareness creation and promotional activities over the 4 years. A total of 804 groundnut demos were successfully set up and the highest number of demos were conducted in Year 4 (*Table 16*). Production and distribution of SSPs was also adopted as a method of popularizing improved groundnut varieties in the country. A total of 2967 t of certified seed was distributed in SSPs by the project in Tanzania over the 4 years, the highest being 1671 t in 2017.
The project used different categories of stakeholders to produce and market improved groundnut seed in Tanzania. On average, about 215 different stakeholders (individual seed entrepreneurs and farmer organizations/groups) were used to produce different classes of groundnut seed annually (*Table 17*). The project intervention led to increased private sector investment in groundnut seed production and marketing in the country. Seed production and delivery heavily relied on farmer research groups, over 400 in number. There were hundreds of individual groundnut farmers and group entrepreneurs producing QDS. Technical skills of these semi-formal seed producers were built by training select groups to enhance their capacities for high quality seed production. Now their entrepreneurial skills should also be built for commercial seed business and linking them with seed companies as contract seed producers.

In Tanzania, QDS production laws are in place. QDS is produced for a specific locality, mostly by the 400 farmer research groups and distribution is restricted to an administrative area where inspection takes place. Quality regulation is managed largely by authorized district inspectors who are generally extension officers with additional training from the formal regulatory board. However, the formal inspectors are required to do the final germination and purity tests that are needed before the seed can be sold. This involves sending samples to a laboratory for testing but does not require inspectors to visit. This approach was used to reach last mile farmers due to challenges in groundnut seed production including limited multiplication rate, rapid quality deterioration and the bulky nature of the crop that discourages heavy private sector involvement. Agricultural Seed Agency (ASA) established to facilitate farmers' access to seed by ensuring sufficient quantities of foundation seed, was not involved in groundnut seed production either. Apart from ASA and the private sector's involvement in groundnut seed systems, the national research institute (Naliendele Agricultural Research Center) was involved in EGS production and engaged farmer research groups as alternative stakeholders.

With improved infrastructure and human capacity, the program began its crossing activities with the support of TL II in 2009/10 by making 10 crosses. By the end of TL III in 2018, the program could manage about 100 crosses per season up from none in 2007 while segregating populations have reached over 500. With TL investment, the program is currently managing 3 generations per season as opposed to 1 generation in 2007 while the breeding cycle is 5-6 years. The program's capacity to evaluate advanced lines has also improved tremendously to more than 500 now, up from 11 before project intervention in 2007 (120 in 2013, 145 in 2014 and 503 in 2017). For a long time, the program's single focus was on breeding for drought resistance. During the project, four product profiles were developed to guide the breeding strategy at the national level (Table 18). The project supported the release of 11 new improved varieties with better yields and resistance to biotic as well as tolerance to several abiotic stress factors (*Table 5*). The summary matrix of the initial picture of the program, specific interventions and outputs are in *Table 2*.

The new approach of seed production and delivery adopted under TL III helped the program produce 12,921.39 t of improved groundnut seed (*Table 6-9*). This constituted about 144.2 t of breeder seed, 1313.89 t of foundation seed and 11,463.3 t of certified seed.

Uganda Groundnut Crop Improvement Program
Before the TL project in 2007, the Uganda groundnut program was not undertaking any crossing activity but just evaluating lines from ICRISAT. Its germplasm base then was just about 600 and there were only 4 testing sites. Its breeding strategy was not guided by product profiles and even the mobility of researchers was limited by the lack of means of transportation within the program. Infrastructure to support breeding and seed production was poor (no irrigation facility). At that time, there were 4 ruling varieties (Serenut 1R, Serenut 2, Serenut 3R and Serenut 4). Groundnut yield was as low as 620 kg/ha and seed production and delivery was very informal resulting into low production of all classes of seed (EGS and certified) and low adoption rates of improved varieties. Neither was there groundnut gender research in Uganda.

With the support of TL III, the program conducted a BPAT self-assessment in 2017 and identified physical infrastructure and human capacity as areas that needed support. Therefore, the project supported the program in developing capacity to develop product profiles that could guide its breeding strategy. Its testing sites have increased under the TL project, from 3 in 2007 to 9 by 2018. These locations are hotspots for GRD, LLS, leaf minor (LM). The project supported the program in establishing a 10-acre irrigation facility and a reservoir with 20,000 litre capacity that have helped in conducting drought phenotyping studies. With additional resources from IFAD and the national government, the irrigation facility has expanded to cover 20 acres and reservoirs with 40,000 litres capacity. This has enabled the program to undertake 3 generations per year. As a result, it takes less than 5 years to release a variety. For example, DOK 1T and DOK 1R which were released in 2019 were developed in 2014. The program is yet to conduct any genetic gains study to measure its progress over the years.

The program benefitted from TL investments in renovating the dilapidated glasshouse which however does not have fittings to control the environment due to lack of funding. The program has 3 storage facilities with no cooling system. Similarly, there are 3 old dysfunctional stores for long term (> 5 years) seed storage that need renovation and the installation of a reliable/permanent power source to support the breeding program to handle seed. Greenhouses are needed for transmission studies. There are 5 laboratory structures with obsolete machines/equipment and unfit to store lab consumables. The program currently outsources laboratory services both within and outside Uganda (Makerere, NARL Kawanda, Nairobi and USA). The program also has 2 tractors, which are shared across the entire institute and a pick-up truck. Also, capacity development to adopt modern breeding techniques have been undertaken. For example, from 2018, all on-station and NPT sites are designed in BMS, barcoded and data collected using tablets. BV is the preferred analytical suite while seed labeling, and packaging is also done using barcodes. The program also adopted electronic seed inventory linked to the barcode to aid seed packaging and tracking seedlots. The championing of the BMS adoption enabled the Uganda groundnut programme to provide leadership in adoption of BMS in Zambia, Malawi and Mozambique under USAID Commissioned Project on Digitalization of Breeding (2018-2019)

A total of 28,225 technology awareness and promotional activities were undertaken to increase the productivity and production of groundnut in Uganda. A total of 26,800 flyers were produced and distributed to stakeholders of 472 FPVS conducted and 587 demos set up. Three books/manuals, six book chapters, two cartoon animations and three documentaries have aided the dissemination of project activities. Farmer groups seem to have been the most popular category involved in groundnut seed production and marketing. The project established 3 MSPs and trained a total of 4,535 MSP members on groundnut seed production and marketing (*Table 19*). Other promotional activities undertaken by the project include the distribution of SSPs among the target communities. A total of 15 t of certified groundnut seed was marketed in SSPs by TL III project in Uganda. In order to produce enough improved groundnut seed, the project promoted the model where multiple stakeholders were engaged in seed production and marketing. Over the last 4 years of TL III, about 3 different stakeholders were involved in the production and marketing of groundnut seed (*Table 20*).

Following project interventions, the program has managed to assemble 1,300 germplasms representing 9 African countries. Based on the BPAT assessment conducted in 2016, it was established that the program had already initiated a crossing program and increased its crosses from none in 2007 to 50 crosses per year with a success rate of delivery of >95% crosses, >90% of seeds per cross and >95% of F2 required by the breeder. Now the program can make an average of 60 crosses per year and an early segregation of about 400. Following the product profile development training conducted under TL III, the program has managed to develop 2 product profiles: (1) Short-duration and climate-resilient varieties with resistance to foliar fungal and virus diseases for oil, food and dual purposes; and (2) Medium-duration varieties with resistance to foliar fungal and soilborne diseases for oil, food and confectionery, and dual purposes. The program received training in genomics and molecular breeding at CEGSB- ICRISAT Patancheru (India). While the program is using marker-assisted selection at a limited scale, due to budget constraints, they are not making full use of genomics (QTL discovery and development and use of molecular markers) at large scale. Similarly, the program is not working on GM as the enabling law is not yet in place and there are no resources to support such research. With TL investments, the 4 old ruling varieties with an average age of more than 15 years in 2007 have been replaced successfully by new improved varieties less than 10 years old on average (*Table 5*). Indicative statistics show that the current market share of program varieties released in the last 10 years are planted on more than 25% of groundnut area, with seed production directly contributing 1.7% in 2018 (*Table 6-9*). The percentage of released varieties coming from the breeding program is more than 80% now.

The impressive adoption intensity figures reported above could not have been possible without a strong and reliable seed production and delivery system. With the involvement of multiple categories of seed producers and marketers, the TL III project supported the production of about 1,939.59 t of groundnut seed in Uganda since 2015 (*Table 6-9*). This constituted 36.69 t of breeder seed, 292.68 t of foundation seed and 1610.22 t of certified seed.

IITA Cowpea Crop Improvement Program

Before the TL project in 2007, the program was not using single-nucleotide polymorphism (SNPs) though it was deploying markers in trait discovery albeit at minimal levels. It was also using to a limited extent a mixture of mass selection, bulk, pedigree, backcross and SSD in its breeding schemes. Data collection and storage was done manually (hard copy field books, IVIS database, and Excel database). The ability of the program to make crosses was limited (less than 60 crosses annually), leading to limited early generation selection and ineffective selection intensity given the small size of populations. Only one generation could be managed per year with limited shuttle breeding. There was no irrigation facility thereby reducing the possible number of generations per year and necessitating redesigning of the breeding pipeline (*Figure 2*). Before 2007, the IITA cowpea program focused mainly on creating populations segregating for drought but more traits have been incorporated with the TL projects' support (phosphorus-use efficiency, bacterial blight, viral diseases resistance, aphid, thrips resistance and Striga resistance). Similarly, before project interventions, there were 2 ruling varieties (IT84S-2246-4 and TVX-3236) released in 1991, 2 varieties released in 2005 while 5 varieties were on the shelf. The ruling varieties remained dominant because no efforts had been made towards variety release and there were also absence/non-functional release committees in the respective countries. There was no systematic efforts for EGS seed production (EGS was exclusively produced by NARS and other research institutes like CGIAR centers). The variety turnover in all the countries was low and few of the improved varieties made their way to the farmers' fields. Seed replacement rate was low because farmers continued to grow predominantly local varieties. There was weak MSP and low private sector engagement in production and marketing of improved cowpea varieties. The area under cowpea was 4,491,000 ha in the region but only 718,560 ha was under improved varieties. A total of 10,576 t of grain was produced using improved varieties. The productivity of improved varieties was 1.5 t/ha compared to the national average of 0.66 t/ha and the adoption rate was 16%.

The TL investments have enabled the IITA cowpea breeding program to modernize significantly. Some of the project interventions to improve efficiency and effectiveness included: undertaking BPAT assessment under TL III project from where recommendations for improvement were made and clear sets of action points were concretized in PIPs such as improving physical infrastructure and human capacity to adapt to modern day breeding requirements. The program started by adopting the shuttle breeding approach where NARS partners were incorporated in research. An example of this is IITA's joint regional trials with IER-Mali, INRAN-Niger, IAR-Nigeria, TARI-Tanzania, IITA-Kano and IITA and IIAM - Mozambique. Digitization of data collection, curation and archiving plus experimental designs using BMS were key interventions by the project to modernize the breeding program. Most of the data is now captured using tablets and recently barcoding for seed storage management. Human capacity development included strengthening NARS capacity by the full or partial support of 8 PhD and 15 MSc students, training on BMS, infrastructure development (irrigation facilities, computer, tablets and seed storage facilities).

Compared to 1 ruling variety in the region before 2007 (IT84S-2246-4), during TL projects, IITA supported the release of 38 new varieties with NARS partners in 7 countries. This was possible because a release committee that meets twice a year to approve/release the varieties is now in place. The program also adopted an inclusive, pluralistic and integrated seed systems approach that recognizes the complementary roles of seed producers such as individuals, seed companies, government organizations, non-government organizations (NGOs) and farmer groups. MSPs were established to bring together actors along the cowpea value chains to interact and link seed producers to seed companies. The program engaged national partners to popularize new improved varieties using various complementary approaches such as demonstrations, extension guides, field days, agric/seed fair and radio/TV programs.

With support from TL investments, the IITA cowpea program is now using markers including SNPs at HPTG platform at Intertek. Its ability to make more crosses increased during the TL project (*Figure 3*); so did its capacity to handle early generation segregating populations, and the number of populations derived from the crossing has improved due to the use of SSD method. The number of generations achieved per year increased from 1 to 3 due to the installation of the irrigation facility that was supported by the TL projects. Data gathering and management, including trial designs and electronic field books, are generated and archived on BMS. Also, with enhanced capacity building through the project, the program has developed 2 product profiles that are guiding its breeding pipeline. These are: (1) Short- and medium-duration grain-type cultivars with large white or brown grain for the Sahelian and Sudan Savanna zones; and (2) Medium- and late-maturing dual-purpose (grain + hay) cultivars with large white or brown grain for the Guinea Savanna zone. The program is yet to conduct any genetic gains study to measure its progress over the years.

As of 2016, the adoption rate of improved cowpea varieties had increased from 16 to 29%. Nearly 30% of the cowpea area is under improved varieties, which is equivalent to over 1 million ha planted to improved cowpea varieties. About 42% of the cowpea producers have adopted improved varieties. This is equivalent to 945,000 households benefitting from improved cowpea varieties. Adoption of improved cowpea varieties is associated with an average 40% yield gain (i.e. 158 kg/ha) among adopters and 17% income gain for sample households.

Most of the time, access to new varieties has been constrained by relying on the formal seed system rather than an integrated and pluralistic approach that caters to various farmers' needs. This has significantly dampened the positive productivity gains of new varieties from the breeding programs. Through project funding, the program developed the iSelect Cowpea Consortium Array through collaboration with the University of California, Riverside and this has facilitated the development of a SNP genotyping platform "Illumina 60k iSelect Bead Assay". This genotyping platform will be used in trait discovery beyond the TL III project.

Mali Cowpea Crop Improvement Program

The Mali cowpea program was using conventional breeding techniques and approaches. It was only using pedigree selection schemes with no genomic tools like MAS, MABC; neither was there digital data capturing, BMS or Genstat. There were no product profiles before the TL project in 2007. The program used datasheets and hard field books for data collection. Genstat discovery was used for randomization and data analysis. The duration for varietal turnover was >10 years. The number of crosses made by the program was very low at only 1 per year and only 1 generation per year with limited target traits and selection at F6. There was only one dedicated cowpea breeder and two technicians. At the onset of the project in 2007, it promoted 9 cowpea varieties in Mali released between 1987 and 1998. Due to very limited financial support for the program to produce breeder seed, there was insufficient seed. There was no suitable harvesting and post-harvest equipment. There were 7 cowpea varieties on the shelf. The annual average production of foundation seed was 1.5 t and that of certified 55 t. There were few seed producers and all activities related to production, distribution and commercialization were entrusted to seed cooperatives. Seed replacement rate was low. Most farmers used local varieties rather than improved varieties. Mean grain yield at farmer's level was between 0.28-0.33 t/ha.

The TL project intervened to improve human and infrastructure capacity of the program. It supported one program staff's completion of PhD studies. The program has developed 2 product profiles that are guiding national breeding activities: (1) Early/medium maturing, Striga resistant with white and large seed size with good yield under drought for Sahel and Northern-Sudan Zone of Mali; and (2) Early/medium maturing, Striga resistant with white and medium seed size with good yield under drought for Sahel and Northern-Sudan Zone of Mali. The irrigation facility has been improved and is being used to speed up generation advancement and off-season breeder seed production. The cold room facility has been restored and the screenhouse renovated. Tablets were bought and staff trained on digital data capturing, curation and archiving on the BMS platform. The program received training in genomics and molecular breeding at CEGSB- ICRISAT Patancheru (India) and already started using MAS, MABC and SSD inbreeding during TL projects. As a result, the number of crosses made increased from 2 in 2008 to 10 in 2018, and the number of generations increased from 1 before the project's intervention to 2. A total of 6 MSPs were established compared to the program target of 4. About 1,421 members of these MSPs were trained by the project in cowpea seed production, management and marketing. The program also embarked on an awareness creation campaign to popularize the new activities. Between 2015 and 2018 during TL III, 4,000 such activities were conducted (*Table 21*). The program also adopted the use of SSP packs and 1,124 t of seed was distributed in the 4 years of TL III. Since 2015, 10 seed producers and marketers have been engaged to produce cowpea EGS and certified seed in Mali (*Table 22*).

With a greater number of stakeholders involved in seed production, there has been an increase in EGS and certified seed production. Over the TL III project's lifetime (2015 – 2018), there has been a general increment in seed production of all classes (*Table 23-25*), but more so in the case of foundation and certified seed classes because of the many stakeholders involved in their production compared to breeder seed that was mainly produced by IER. In general, 1,980.19 t of cowpea seed was produced in the 4 years of TL III in Mali. This constituted 7.92 t of breeder seed against a target of 8 t, 104.79 t of foundation seed compared to the 213 t target and 1867.48 t of certified seed against a target of 3,200 t. This impressive increase in the amount of certified seed produced together with awareness creation and promotional activities, led to an increase in the number of varieties adopted by farmers from 7 to 11. A total of 2 old varieties have been phased out due to promotional activities coupled with the SSP model. The MSPs have promoted sharing of information and knowledge between different cowpea seed value chain actors.

ICRISAT and IITA worked with farmer seed producer groups and cooperatives in Mali and with the national research agency, IER for variety testing, selection and dissemination. Coopérative Sikolokoloton in Mali produces certified seed of cowpea and groundnut besides millet, sorghum and maize that it distributes in its own region. It has its own seed treatment and conditioning unit with a capacity of over

10 t per day. Union Locale des Producteurs de Cereales (ULPC) and Co-opérative pour la Promotion de la filière Semencière du Mandé (COOPROSEM) use the web, together with local radio, to reach farmers. COOPROSEM sells its seeds directly to members but also partners with seed company Faso Kaba for contract seed production. Two of the main cooperatives specifically address women, either through groundnut seed multiplication or through training in inputs and equipment handling. An interesting dynamic was observed on a cowpea field during monitoring visits, where a women group had husbands to support them in different stages such as land preparation, weeding and harvesting at no extra cost.

Nigeria Cowpea Crop Improvement Program

Before the TL project in 2007, the Nigeria cowpea program was using traditional breeding methods and techniques like bulk selection. Physical infrastructure was either missing or dilapidated. The program was not using genomic tools and even data collection and analysis were manual. The average number of crosses made at this time was about 5-10 per year using conventional breeding schemes of single cross and bulk segregation. The program was not involved in early generation selection but received advanced lines for evaluation. Infrastructure was dilapidated -- 3 poorly maintained screenhouses. There were 5 released ruling varieties with an average age of more than 20 years (Ife Brown, TVX-3236, Sampea 7, IT84S-2246-4 and Sampea 9). Breeder seed production ranged between 0.6 -1.0 t per year. The most popular seed delivery model was farmer-to-farmer. Varietal turnover was more than 6 years with seed replacement duration being more than 10 years. There was no MSP.

Under the TL project, the program underwent BPAT self-assessment from which PIP was developed and implemented systematically to improve breeding deliverables. Physical infrastructure and human capital were enhanced with the support of TL projects. The project supported the installation of an irrigation facility, procurement of a water pump, and renovation of a screenhouse. Short-term trainings were conducted in product profile development, the use of modern handheld electronic devices to collect data, data curation and archiving using BMS. The project also supported the program in creating linkages between seed producers and grain marketers. The program also created synergies with and leveraged outputs from in-country projects like the USAID-funded Cowpea Upscaling Project (ended December 2017) BMGF PEARL project and N2Africa project.

The program also engaged in promotional activities to create awareness about varieties to facilitate increased adoption, production and impact. Under TL III alone, 13,780 promotional activities were undertaken, comprising about 298 demos, 9 field days, 8 agri-seed fairs/exhibitions/shows, etc. (*Table 26*). The program was also supported to increase the technical and management capacity of its stakeholders in seed production. Seven MSPs were established against the project target of 4. About 13,220 members of these MSPs were trained in good seed production, management and marketing practices apart from being exposed to specific training modules on the safe use of pesticides, harvesting and post-harvest handling, and seed digital roadmap.

To scale up seed production and incorporate sustainability, the project supported the program in engaging with the private sector and other seed value chain actors in seed production and marketing. By the end of TL III in 2015, an average of about 397 different actors had been involved (*Table 27*). The project also supported the program in producing and distributing about 2,738 t of improved cowpea seed in SSP.

The adoption of modern breeding tools after TL interventions resulted in an increase in the number of crosses made from 5-10 prior to 2007 to more than 50 currently. The number of lines nominated to preliminary yield trial (PYT) are now over 30 compared to just about 10 in 2007 while the number of advanced lines received from IITA for evaluation has increased to more than 800 [RILs, MAGIC (300), MARS (160) derived lines]. The number of both on-farm trials and demonstration sites have increased from 30 to 100 per year. With improved infrastructure (irrigation and screenhouse), the cowpea program is now achieving about 3 generations a year. The product profile development training resulted in the development of 6 cowpea product profiles for Nigeria (*Table 28*). Trial design, nursery development, data curation and seed inventory organization are being done in BMS. Data capturing, handling and curation is done electronically. The program received training in genomics and molecular breeding at CEGSB- ICRISAT Patancheru (India). With TL support, the program started using modern breeding methods like pedigree, backcrossing, SSD and developed phenotyping protocols. The program has released 9 improved cowpea varieties (*Table 5*). The production of breeder seed increased from 0.6 t in 2007 to 2.61 t in 2015 and further to 6.95 t in 2018. The same trend was seen in foundation and certified seeds (*Tables 23-25*), with production of foundation seed going up from 7.3 t in 2007 to 46.1 t in 2015 and further to 532.5 t in 2018 and that of certified seed increasing from 75 t in 2007 to 751 t in 2015 and 4566 t in 2018. The programme have purchased two threshers to enhance breeder seed processing. Following the training conducted under IITA-Bayer-NARS project, the program initiated a genetic gain assessment which was established across three agro-ecologies representing; Sahel savanna, Northern Guinea Savanna and Sudan Savanna. The purpose is to assess the yield trend of the commercially released varieties (20 years to date) in Nigeria in different target environments.

Best-fit seed production and delivery models were identified i.e. Community-based seed production scheme with support/facilitation of NASC. Old varieties such as Sampea 7 (released in 1985) have almost been completely replaced by newer varieties such as Sampea 8 (released in 2005) promoted under TL projects since 2007. Better still, Sampea 8 was quickly replaced by Sampea 11 (released in 2009) which is quickly being replaced by Kwankwaso which is popular but is yet to be officially released. A brief summary of how the program looked like, specific TL project interventions and actual outcomes can be accessed in *Table 2*.

Burkina Faso Cowpea Crop Improvement Program

Before TL project interventions, the Burkina Faso cowpea program was using conventional pedigree and backcross breeding methods. Infrastructure and human capacity were inadequate and only 1 generation was possible in a year. The program's crossing activities were meagre (about 10 in a year) and the program evaluated advanced fixed lines from IITA. Data capturing was done manually. The program was using excel datasheets and hard field books to collect data. Genstat discovery was used for randomization and data analysis. The varieties that were being promoted were the ones released in 1986. There was no support for breeder seed production hence the quantities produced were less than 0.6 t/year. The adoption rate of improved cowpea varieties in Burkina Faso was less than 15% (farmers grew predominantly old local varieties). The variety turnover was more than 10 years and seed replacement rate ranged between 3 and 5 years. These varieties were low yielding and susceptible to many production constrains. Breeder and foundation seed were solely produced and sold by INERA and the money from the sale was used to support the next production phase. There was no private sector involvement in cowpea seed production and marketing and no MSP platform then.

In order to enhance awareness and stimulate adoption, the project has been supporting the Burkina Faso cowpea program to undertake technology awareness and promotional activities such as demos, field days and agri-seed fairs/exhibitions/shows. During TL III, 13,722 promotional activities were undertaken (528 demos, 20 field days and 5 agri-seed fairs/exhibitions/shows) (*Table 29*). Four MSPs were established by TL III and 3 other MSPs have been created under other project initiatives in collaboration with the INERA cowpea team. These MSPs have been useful tools in training stakeholders in seed production, marketing, and best agronomic practices. Under the 4 MSPs established and 2,678 members trained. These platforms have also created linkages with local vendors to collect grain from producers. In Burkina Faso, apart from the seed subsidized by the government, all the seed is sold in SSPs of 3 kg (for 0 .25 ha), 6 kg (for 0.5 ha), 12 kg(for 1 ha) and 15 kg (for 1 ha). In TL III alone, 615 t of certified cowpea seed were distributed in SSP.

Leveraging on TL project funds and other sources, the program was able to renovate its irrigation facility and cold room, and a generator was bought to power these facilities. A thresher has been ordered using resources from TL III. Long-term capacity building included the training of 2 breeders at PhD level while short-term trainings included those on BMS and the use of handheld gadgets to collect field data. Tablets, SPAD-meter and leaf-parameter were bought by the project to facilitate digitized data collection, curation and archiving. Program staff were trained in product profile development and gender mainstreaming in breeding activities. The program also engaged the private sector in seed production, especially of foundation and certified seed. By the end of TL III in 2015, an average of 150 actors had been involved in seed production each year (*Table 30*), majority of them individual seed entrepreneurs and farmer organizations/groups.

With TL support (including training and collaboration at CEGSB-ICRISAT, Patancheru) and other projects and organizations like USAID, UC-Riverside, the program is now using modern breeding techniques (MAS, MARS, MABC, SSR markers and SSD). Besides, the program is now using modern gadgets to collect data, curate and archive (BMS). With enhanced breeding capacity, the program is currently achieving about 3-4 generations per year compared to 1-2 generations before TL project intervention. The number of crosses made have increased from 10 at the beginning of the TL project in 2007 to more than 30 per trait by the end of TL III in 2018. From the product profile development training, 3 product profiles have been developed to guide the cowpea-breeding program: (1) Early maturing, Striga resistant with white and large seed size with good yield under drought for Sahel and Northern-Sudan Zone of Burkina Faso (40% export, 60% domestic use); (2). Early/medium maturing, Striga resistant with white and large seed size with good yield under insect infestation for Sahel and Northern-Sudan Zone of Burkina Faso (40% export, 60% domestic use); and (3) Striga and Brown blotch resistant with white and large seed size with good yield for South-Sudan zone of Burkina Faso (40% export, 60% domestic use). The program has also developed several improved cowpea lines using molecular breeding tools with support of TL and several other projects like Kirkhouse Trust, Feed the Future Lab on Cowpea at UC-Riverside, IITA.

Production levels of the three seed classes have increased over the years. A total of 5,239.95 t of cowpea seed was produced in Burkina Faso during the TL III project (2015 – 2018), comprising of 25.62 t of breeder seed, 836.17 t of foundation seed and 4378.16 t of certified seed (*Tables 23-25*). A greater amount of certified seed has translated into adoption rate going up from 15% to 40%. There is increased cowpea production in the intervention area and many new products derived from cowpea processing are in place (bread, flour, cakes, biscuits, etc.). A summary of how the program has changed over time with the support of TL projects can be accessed in *Table 2*.

Ghana Cowpea Crop Improvement Program

Before the TL project in 2007, the cowpea program in Ghana was using traditional breeding methods (no molecular markers), collecting, and archiving data manually. No crossing work was being undertaken and most of the work involved evaluation of advanced lines from IITA. Only 1 generation was feasible at that time. Even FPVS did not form part of variety evaluation by then. Although 4 varieties were released, they remained on the shelves. Few quantities of EGS and certified seeds were produced and less than 10% of farmers used improved seeds. Seed production was left to the grains and legumes national board under the Ministry of Food and Agriculture. The private sector was not engaged in seed production and marketing. There was less extensive promotion of released varieties because of limited resources and few communication channels. Farmers preferred using their own seeds from previous harvest or buy grains to be planted as seeds. There were poor links to both seed and grain markets.

Infrastructure improvement and building of human capacity within the program were key areas of focus. Starting with infrastructure, the screenhouse and irrigation facility facilities received a significant facelift with the support of TL project resources. Molecular tools have also been introduced to facilitate breeding work in the program. FPVS have been imbedded in the variety evaluation process with the support of the TL project. Electronic data capturing via handheld gadgets provided by the project has now been institutionalized within the program. Newly introduced breeding materials received from IITA have been evaluated in multi-locational yield trials and on-farm demonstration trials. FPVS have been used to evaluate advanced lines that were most preferred by farmers and genotypes that did not meet farmer/consumer preferences were improved upon by making crosses with those with desirable traits. Demonstrations of good agronomic practices (GAPs) for cowpea production, spraying regimes and use of host-plant resistance to control *Striga gesnerioides* were carried out to help farmers maximize their yields. Technology promotional materials (production guides, flyers, leaflets and manuals) were distributed to all the target cowpea-producing communities and other promotional activities undertaken. During the TL III project, 6,166 activities were undertaken, consisting of 220 demos, 32 field days, 2 agri-seed fairs/exhibitions/shows, etc. (*Table 31*).

Data captured using tablets has increased the efficiency of phenotypic evaluation. The use of partially replicated designs has enabled the evaluation of a larger number of breeding materials or populations. With the advent of the BMS, trial design, trial management, data management has been improved. This has helped to avoid losses in selection accuracy that may have resulted in errors in data management. Breeding operations have been improved, through segregation of tasks or division labor. Individuals have been designated for a set of activities within the breeding program. For example, there are personnel solely responsible for trait development, planting, managing and harvesting trials. There are also designated individuals at six multi-locational test sites to ensure that the breeding operations are executed correctly. Meetings organized prior to the beginning of the season helps to share ideas on best practices to achieve the desired genetic gains. Testing of hybrids by using molecular markers has also helped to discard crosses that were not successful, thereby increasing selection accuracy. Off-season nurseries have been used to increase the number of generations achieved in a year. Irrigation sites are rented and used for dry season trials and this enabled an additional growing season.

In order to popularize improved cowpea varieties in Ghana and increase access of improved seeds to smallholder farmers, 1,155 t of improved seed was distributed in SSPs during the TL III project alone. Similarly, in order to build the capacity of cowpea seed value chain actors, 8 MSPs were established in Ghana and about 10,842 members trained in good practices of seed production, management and marketing. Community seed production schemes have also been adopted by the program to increase seed production in a sustainable way. The program engaged private sector actors in seed production and an average of 83 actors were engaged each year to produce and market different seed classes of cowpea during the 4 years of TL III (*Table 32*).

With project support including training in genomics and molecular breeding at CEGSB- ICRISAT Patancheru (India), and BMS, the program adopted modern breeding techniques, and by 2016 the program had started making crosses using SSD, pedigree, backcrossing and an average of about 15 crosses per year compared to none before project intervention in 2007.The program started carrying out generation advancement and initial evaluations of selected lines from advanced generations using RCB and partial lattice design. By the end of TL III in 2018, the program had increased its crosses to about 20 and 2 generations from 1 generation per year as a result of infrastructural improvements made with TL project support since 2007. By the end of the project in 2018, a total of 9 varieties had been released since project inception in 2007 (*Table 5*) and 6 have been selected for release. The breeding program is now guided by a product concept based on consumer preferences. Several segregating populations are available for characterization and evaluations to select best performing lines that conform to the developed product profiles. BMS has been adopted and used to manage trials, crosses and nurseries. In addition, BMS is being used for managing ontology and importing germplasm data. Hence data handling is more efficient.

Seed production has increased across the three classes (*Tables 23-25*). The project supported the cowpea program to produce 3324.47 t of cowpea seed under TL III alone, comprising of 7.67 t of breeder seed, 1689.4 t of foundation seed and 3324.47 t of certified seed. By using mass media and field demonstrations, improved cowpea varieties Padi-Tuya, Kirkhouse Benga and Wangkae released by CSIR-SARI have been popularized and are now in high demand by farmers in Northern Ghana. Recent varieties released and candidate lines have preferred demand-driven characteristics such as white seed coat with black eye, bold seed, early maturity (60-70 days), are resistant to insect pests, Striga and drought and have a short cooking time. Selling of seeds in SSPs (0.5, 1, 2 and 5 kg) was a good marketing innovation to enable smallholder farmers to easily buy any quantity of their choice.

CIAT Common Bean Crop Improvement Program

The CIAT common program was majorly using traditional breeding techniques and approaches before the TL project in 2007. However, it was utilizing gel based marker platforms (RAPD, SSR and SCAR) for disease resistance to conduct marker assisted selection (MAS) to a limited extent. Physical infrastructure and human capacity were not up to date for the program to deliver on its expectations in the region and globally. With the support of resources from the TL projects and other projects, the program has consistently been improving its infrastructure, human capacity to meet its demands and advance in breeding technology. Before the TL project in 2007, the variety turnover was 8-10 years, and there was low private sector interest in common bean seed production and marketing. Breeder seed was produced by NARS whereas foundation and certified seed were produced by very few formal seed companies.

The common bean program at CIAT benefited from TL investments starting from Phase 1 in 2007. When the TL II was initiated in 2007, breeding for drought tolerance in common bean had received only sporadic attention in East and Southern Africa. Under the TL I project, drought gained prominence and moved into the research agenda. During Phase 1, the program focused on developing genomic tools, developing drought tolerant lines, germplasm deployment, creation and strengthening of partnerships, human and infrastructural capacity building of NARS and distributing varieties that were on the shelves in 6 countries (Ethiopia, Kenya, Tanzania, Uganda, Malawi and Zimbabwe). The program also conducted germplasm characterization and got 3 classes: water savers, moderate savers and water spenders. During Phase 2, the program continued with its efforts of developing the genomic tools and merging them with those that had already been developed by TL I. During TL III, the countries of focus reduced from 6 (Ethiopia, Kenya, Uganda, Tanzania, Malawi and Zimbabwe) to 3 (Ethiopia, Tanzania and Uganda). The program began utilizing the genomic tools that it had developed in Phases 1 and 2 (GWAS, SNP Platform, genomic predication). It also began using SSD in generation advancement. To modernize its infrastructure and equip its staff with current skills in breeding, the CIAT common bean program bought Matson cooker and photo box seed analyzer. Equally important is that the program staff were trained on product profile development during TL III. This training enabled the program team to develop 7 product profiles (*Table 33*).

Apart from internal capacity enhancement, the CIAT common bean program used TL resources to build the capacity of its NARS partners in target geographies through long-term trainings, i.e. 5 PhD degrees and 10 MSc degrees. Short-term courses were conducted with the support of TL for common bean technicians (on crop physiology, monitoring of soil water content, estimation of biomass at mid-pod fill, components of harvest index at harvest time, electronic data collection, statistics and BMS) and for scientists (on IBP, BMS hands-on training, demand-led breeding, SNP markers introduction, HTPG workshops, GREAT training and PABRA breeder's workshops). In order to attract seed actors and to scale up production and delivery of seed, the program created a grain market off taker pull, that decentralized farm-based production of QDS and encouraged a multi-actors approach for enhanced seed production and access (*Figure 4*). CIAT initiated the licensing of varieties to some commercial companies. By the end of TL III project in 2018, the program had engaged a total of 622 actors in the 3 TL III countries in seed production as opposed to 13 actors in 2007. The program created a pull and push strategy, promoted SSP approach (1, 2, 5 and 10 kg seed packs). Currently, about 25% of common bean in target countries is distributed in SSPs. The varieties are also bundled with seed dressing chemicals such as Apron Star®.

By end of TL III, the program was utilizing more than 4 genotyping platforms including HTPG platform at Intertek and several SNP-based markers had been identified (*Table 34*). Modern data collection, curation and archiving techniques have been adopted by the program at different levels. For example, in 2018, the decision to implement BMS as the breeding data management system at CIAT HQ was made and BMS server installed. Data entry is ongoing currently, and available data is being moved from a test server to the "production" server. A cloud-based server will be installed for the CIAT-PABRA network to give quicker access to African programs. However, its usability in Uganda will require an additional server linked to the HQ server and institutionalization of BMS by CIAT. Most of the breeding data of the CIAT-Uganda program are being uploaded at CIAT HQ in Colombia with support of the IBP team.

Product profiling by the program is still in preliminary stages. Nutrition profiling requires more in-depth studies. Breeding program phenotyping and genotyping capacity is still low. On the other hand, advances in combining drought tolerance with other traits, especially biofortification in Andeans and bush types has also been slow. New consumer traits (e.g. short cooking time, Fe and Zn grain content, canning quality, colour retention etc.) are slowly gaining traction in the breeding pipelines. Decentralised and diversified seed production and supply including farmer-based approaches are instrumental in meeting seed needs and disseminating new varieties – recent phenomenal gains in QDS production include new varieties. Investment in private seed sector development is most likely to succeed with a push-pull strategy. The TL investment in CIAT's common bean program has supported the development and release of 104 improved, market-preferred varieties with better agronomic suitability in 6 target countries.

The BPAT conducted during the first year of TL III made several findings and recommendations for action:

- The field at the Kawanda station was found to be highly variable, causing confounding effects on trial data. It was recommended that CIAT purchase a land leveler, disc and harrow for Kawanda. In response, a tractor, disc harrow and leveler were purchased.
- The program was accomplishing only two generations per year. To accomplish four generations per year, increased work space and drying equipment was needed to reduce time between harvest and replanting. The breeding nursery needed to be at a location warmer and dryer than Kawanda. Besides, irrigation equipment was needed. In reaction to these recommendations, a movable drying shade was acquired and irrigation facility established that enabled the program to achieve four generations per year. The program is considering a warmer and drier site in northern Uganda to enhance its effectiveness in drought phenotyping and seed production.
- It was observed that the program creates about 100 new populations annually. Moderate selection is exerted during inbreeding generations generating approximately 15,000 F5 lines. These are evaluated visually to select about 400 for entry into yield trials. It was recommended that the number of populations created annually should double in order to fulfill the needs of 7 or more market classes and climbing versus bush beans. Steps were taken to have at least 50 new crosses targeting specific traits in specific market classes each year. Currently, over 2000 lines are in yield trials with partners in target countries.
- The program evaluated about 5 different PYTs annually with an average of 80 new lines in each (up to 400 lines are evaluated). Selection intensity from the PYTs was low (50%) to minimize reduction of genetic variability needed in various agroclimatic zones. It was recommended that the number of entries in PYT should be increased by at least 100%. As a result, the number of PYTs was tripled.
- A growth chamber was observed to be necessary for pathology. A temperature controlled foliar disease screening chamber was installed in the short run.
- The use of molecular markers (2000 samples annually) was observed to be too low to have a significant impact. The labs were observed to be very good, but samples were analyzed by electrophoresis and scored manually. The plans were to sample approximately 30,000 per year in 2018. Lab space is adequate, but robotized sample handling would be needed. It was recommended that Kawanda switches to modern technologies with automated reading capabilities (chip). Kawanda could be a Regional Crop Improvement Hub for common bean but could also serve other crops. All released varieties need to have a high density fingerprint. The program enhanced its collaboration with various institutions for genotyping, including Cornell University for Genotyping by Sequencing (GBS), DArT on a common genotyping platform at IGSS-BecA, Eshires Lab, SNP genotyping at KBioscience, UK and Shared genotyping facility for the CGIAR (HTPG Platform) at Intertek.
- Drought is a major focus of dry beans in ESA but there was too much rainfall in Kawanda to be a useful location for drought studies. In addition, there would be need of a physiologist to conduct drought studies in different locations in ESA. Drought trials are being conducted off-season but surprise showers are very common making this inadequate. Two rainout shelters are needed: 15 x 30 m each. A solar powered irrigation facility for off-season trials has been installed. A drought phenotyping site is currently being sought but this requires additional manpower.
- The program also started phenotyping for canning quality adapted from Michigan State University (MSU) protocol, Phenotyping Common Beans for Symbiotic Nitrogen Fixation (SNF), a protocol for field evaluation. Under AVISA, the program is advancing to micronutrient analysis using X-ray florescence (XRF) spectrometry and inductively coupled plasma spectrometry (ICP).

Ethiopia Common Bean Crop Improvement Program

The Ethiopia common bean program joined the TL project in 2011. Before this, the program was using traditional breeding approaches (no genomic tools, manual data collection and analysis, etc.). Even after the end of TL III in 2018, the program still does not have a glasshouse and most of its farm operations are not mechanized, except ploughing. The pathology lab available is shared with 3 other programs and is poorly equipped. The seed store has no temperature and humidity control equipment though there is a very small cold room that is shared with the sorghum program. Irrigation facilities too are inadequate. Before the TL project interventions, the program could only manage 1-2 crosses. At that time, most of its work was to evaluate fixed lines received from CIAT. The program was undertaking one generation in a year. The program was using single and double crosses for disease (rust, CBB), drought resistance and/or canning quality. The program was using Excel sheets for data compilation. A number of local postgraduate students were supported through the research under TL project. The program had a seed store for long-term storage that needed renovation and equipment. Basic farm implements for land preparation were available. A total 19 common bean varieties had been released in Ethiopia and 9 varieties were on the shelf. By 2007, there were 2 main ruling varieties that were released as early as 1970 (Mexican 142 and Red Wolayita). There was no variety turnover and seed replacement rate was minimal. Breeder seed production was financed by government funds and PABRA and less than 1 t/ha was produced in 2007/8. EGS was being produced by research institutions and certified seed was produced by public and private seed producers. Foundation seed production in 2007/08 was 60 -100 t/year while certified/QDS was 500 t/year. The main promotional/awareness creation approaches were pre-extension demonstrations by research extensionists and the Ministry of Agriculture. There were no MSPs, but there was one common bean steering committee made up of multi-stakeholders who support bean promotion. Private sector engagement was mainly focused on grain export and trading, but there was very limited engagement of the private sector and community-based organization in seed production and delivery.

With TL intervention, data handling improved. Breeding efficiency has been improved 3 generations per year as a result of enhanced field and lab phenotyping through provision of standard screening protocol and shared phenotyping facilities." This has been achieved through the provision of a controlled crossing greenhouse and water supply system. The 2 ruling varieties before TL projects have been replaced with TL-promoted varieties (Mexican 142 replaced by Awash 2, Awash Meten, SAB 636 and SAB 732; Red Wolayita has been replaced by SER 119 and SER 125). Breeder seed production has increased from 3.4 t in 2011 to 20.7 t in 2018 (*Tables 35-37*). Currently, 9 out of 59 varieties dominate the market with an estimated area coverage of 10 -15%. Breeder's estimate of the current market share of the 5 varieties and germplasm from EIAR and other territories released in last 10 years is 10-25%. About 30% of released common bean varieties have more than 70 ppm Fe and more than 30 ppm Zn. TL III project has supported the Ethiopia common bean program to produce a total of 20,422.73 t of seed, comprising of 53.63 t of breeder seed, 915.58 t of foundation seed and 19,453.52 t of certified seed (*Tables 35-37*). Increased private sector and seed enterprises investment have significantly contributed to increased seed production in Ethiopia. The government of Ethiopia has legalized QDS and seed certification labs have been decentralized. The program received training in genomics and molecular breeding also at CEGSB- ICRISAT Patancheru (India).

The technological progress in the form of varietal change and improved agronomic practices have combined to provide positive growth trends in common bean productivity in Ethiopia. For example, yield grew from 1.0 t/ha in 2008 to about 1.7 t/ha in 2016. After accounting for confounding factors, the adoption of improved common bean varieties increased the average yield of beans by 0.336 t/ha, while their technical efficiency has increased by 5%. Food consumption of adopters rose by 9 points and poverty prevalence reduced by 4%. If we limit the analysis to sizeable number of districts where the Tropical Legumes Project Technology promotion activities were concentrated, the gain from adoption of improved seeds is doubled, suggesting the potential gain awaiting bean farmers when barriers associated with information and access are overcome. The national adoption rate of improved varieties in Ethiopia is about 37% of bean growers, which translates to about 1.5 million households. Variety Mexican 142 that was controlling over 50% of the white canning bean market class and Red Wolayita variety that was controlling about 70% of the red cooking bean type at the time of baseline studies in 2009 have been replaced totally by new varieties promoted under the project.

A study was recently conducted in Ethiopia to assess selection gains or genetic progress, determine deficiencies, redefine objectives, and adjust breeding priorities that can improve effectiveness of the breeding program. In the large-seeded beans set, the mean grain yield percentage varied from -31 to 6% over the oldest variety. Genetic progress in grain yield was statistically non-significant, although annual genetic gain was 4.31 kg ha-1 yr-1 (0.16% per year). Improvements were also found in traits such as plant height (0.44%) and pods per plant (0.82%). In the medium-seeded set, this study did not find significant response of grain yield to year of variety release. To the contrary there was an annual genetic reduction of grain yield at a rate of 45 kg $ha^{-1}yr^{-1}$. The only improvement was found in 100 seeds weight. It increased at a statistically significant rate of 0.39 g $year^{-1}$ (1.19% yr^{-1} over the oldest released variety). In the small-seeded set, linear regression of yield on year of release was not-significant although grain yield increased at a rate of 1.67 kg $ha^{-1}yr^{-1}$ (0.08% relative to the first released variety, Mexican-142). Statistically significant responses were found in traits such as days to flowering (-0.02% per year), days to physiological maturity (-0.04% per year), and 100 seed weight (0.56% per year).

Adoption surveys indicated that 13% of bean growers have adopted varieties supported under the project, while 29% of the households classify their varieties as improved but did not know the variety names. The average number of years a variety is grown on a farm ranges from 6 to 9 years, with few farmers maintaining the same variety longer than 20 years, which contributes to slow varietal turnover. Study findings show that farmers in the top economic strata keep a variety for a significantly fewer years and are also likely to obtain improved variety of seed from formal systems. These results suggest that over-reliance on the slow informal seed systems partly explains low varietal turnover. Varieties vary in their adoption trajectory, with some varieties such as Nasir (released in 2003) taking a shorter time to diffuse to users while others like Awash 1 released in the 1990s have seen a steady rise in adoption by farmers, especially between 2009 and 2016. We hypothesize that there are some specific traits that cause some varieties to diffuse faster than others; this has not been answered in the study and will be addressed under the AVISA project.

There has been an accelerated rate of new variety uptake in the last decade that can be credited to the TL project. An overwhelming majority of adopters first learnt of the respective improved varieties between 2006 and 2016, during the project life. Information dissemination pathways have been horizontal [from fellow farmers (81%)] as well as vertical [via Government/NGO training, field days, field demonstrations and extension visits (70%)]. High quality seed of improved varieties diffused via formal and informal seed systems as the dissemination pathway with formal systems supplying 18% of the market share, while the informal sector supplied 30% of seed needs per year. However, there has been a gender bias in seed dissemination pathways, with men farmers in economically well-to do households more likely to access improved variety seed from formal dissemination pathways while poorer and women farmers concentrate on informal dissemination pathways, requiring gender integration strategies to address biases in the follow up activities.

The analysis of yield differences between households headed by male and female farmers suggested a significant yield gap of more than 0.6 t/ha in favor of male-headed households. The economically poorer households obtain about 0.2 t less than farmers in the top economic strata.

Despite the excellent work in seed systems, gaps in seed supply persist compared to the bean seed demand in the country. Therefore, more seed production is indispensable. The government has set a bean yield target of 2.5 t/ha by 2025 – this will require a large scale supply of seed from the current production of around 5,000 t to 10,000 t (representing 20% of annual bean seed required). To achieve these targets, the program aims to: (i) build the capacity of private sector/seed entrepreneurs to produce and market high quality seed of improved varieties; and (ii) reduce further the time lag between release and wider use through rigorous promotion awareness campaigns.

Though common bean is a cash crop and steps have been taken to involve the private sector, investment in seed remains low. Private seed enterprises and farmer cooperative unions will continue to be key actors. However, there are emerging seed entrepreneurs that if well supported (e.g. through access to EGS, expanding agro-dealership networks, commercialization of SSPs, skills and knowledge access), will open up new seed market opportunities. At the beginning of the TL project, SSPs were being distributed free to farmers, but now these packs are being sold, indicating the sustainability of the intervention.

Tanzania Common Bean Crop Improvement Program

When the TL project started in 2007, the Tanzania common bean program there had inadequate human and infrastructure capacity to support its breeding program to deliver on its national mandate. The program was using conventional breeding techniques (pedigree and bulk breeding). Data collection and archiving were manual processes and data was managed in Excel sheets. The program used to make an average of about 7 crosses per year. Only 50 fixed lines were being evaluated per year. Average breeder seed production was 6.2 t annually. There were inadequate linkages between common bean seed production, grain production and the markets. There was inadequate demand creation of quality seed of improved varieties as farmers were not aware of improved bean varieties and their commercialization and where to source them. Private sector engagement and incentives for farmers to take up improved varieties were lacking. There was low involvement of women in participatory technology selection (PTS) activities and on-farm trials (about 20%). There was limited use of laborsaving equipment in bean production, leading to 95% drudgery that was largely borne by women. There was no gender scientist and sex disaggregated data was too limited to inform interventions and evaluation of gender outcomes.

The TL project was instrumental in modernizing the Tanzania common bean program. Both physical infrastructure and human capacity were improved. Long- and short-term trainings were supported by the project and required equipment and implements provided. At least 5 students were supported in their MSc and PhD studies (1 female and 4 male). BMS trainings were conducted to enhance skills and now BMS is used in field planning, data gathering and management. Data collection is done using tablets purchased with TL III funding and the number of trials being uploaded on BMS have been increasing since the start of TL III (1 in 2015, 10 in 2016 and 15 in 2017). The pathology labs at SARI and Uyole were poorly equipped and maintained, at least based on the BPAT report. There were inadequate seed processing and storage facilities. Even the netted screenhouses at SARI and Uyole were poorly maintained. However, with TL project resources, the screenhouses have been renovated and cold room and irrigation facilities installed.

The program developed grain market pull through bean business corridors (3 major corridors for Tanzania). It also engaged grain traders (offtakers) based on market preferred types/varieties in the establishment of common bean business corridors e.g. red mottled, yellow, sugar, DRK and Kablanketi. It developed adequate information on varieties through agro-dealers and seed companies led demos. The program diversified its actors who are engaged in production of various seed classes. For instance, TARI research farm was engaged to produce EGS in a commercial and sustainable way. On average, about 289 actors were engaged each year of TL III in Tanzania (*Table 38*). As a result of the interventions, the program increased the production of breeder seed from 6.2 t in 2007 to 45 t in 2018; basic seed from 94 t in 2007 to 480.5 t in 2018; and certified/QDS from 165.2 t in 2007 to 4,950 t in 2018.

In order to promote the adoption of improved common bean varieties in Tanzania, the program undertook several awareness creation and promotional activities among the targeted communities in the country. These included demos, field days, agri-seed fairs/exhibitions/shows, etc. (*Table 39*). During TL III project (2015 – 2018), the program conducted 829 demos compared to 200 that were targeted; 328 field days compared to 40 that were targeted; and 22 agri-seed fairs/exhibitions/shows compared to 20 that were targeted. The program created 41 MSPs and trained 6,986 seed value chain actors on seed production and delivery models. Beside this, the program distributed about 517 t of improved seed in SSPs. Tanzania public and private seed companies moved from 50 kg seed bags in 2015 to 2 kg bags selling 542 t in 2017. In terms of seed production, the TL III project supported the Tanzania common bean program to produce a total of 7535.6 t of common bean seed, comprising of 87.6 t of breeder seed, 1116.54 t of foundation seed and 6331.46 t of certified seed (*Tables 35-37*).

After TL project interventions, the program adopted modern breeding methods (e.g. SSD) and approaches (product profiles). It is now making about 45 crosses per year up from the 7 crosses that were being made in 2007. The breeding scheme has now changed from the old pedigree and bulking to double and triple crosses and diallel mating design. With physical facilities improved (irrigation, screenhouse and cold storage), the number of generation advancement has increased from 2 to 3. The product profile development training given to its staff has enabled them to develop 7 product profiles that are now guiding the national breeding agenda (*Table 40*). With the TL project, 21 common bean varieties have been released in Tanzania (*Table 5*), of which 11 were released during the TL III project while another 8 were submitted for DUS/NPT by the end of TL III project in 2018.

Gender mainstreaming in common bean production and marketing has significantly increased incomes The project has increased employment opportunities for youth and men through manufacturing of bean grain threshing machines. Use of machines and herbicides in bean production has helped in reducing drudgery for women. For example, Byda Agrovet Company in Mbulu, Manyara District, is a seed company that has 5 different outlets in Tanzania and has employed 24 workers. Byda specializes in selling seeds directly to farmers. The company obtains seed from TARI-Selian. There are 49 such private sector start-ups moving to sustainably scale up bean seed supply. This is besides engagement with larger seed companies such as East African and Beula Seed.

An adoption survey conducted in 2016/2017 shows that nearly 50% of the households were growing improved varieties but only 33% households grew varieties promoted under the TL project in 2016. There were early adopters of varieties released during the project life, i.e. in 2008 and afterwards, but there were also farmers who still plant varieties that were released more than two decades prior to the survey. The area weighted average age of a variety in this region is 18 years. Results from a multivariate analysis of variety choice suggest that rapid varietal replacement could be constrained by low use of soil fertility management inputs (such as chemical and organic fertilizers), seed recycling and poor access to seed of new varieties. The study findings indicate that farmers tend to match varieties with soil characteristics; they plant new varieties on soils that are relatively fertile while allocating a mixture of varieties (i.e. new, old improved and landraces) to soil of poor fertility, thus adopting new varieties partially. Limited fertilizer use in bean production demonstrated in this study and previous research make farmers prefer varieties that can perform well under low soil fertility conditions, usually landraces.

Evaluation of the impacts of new variety adoption on crop productivity, profitability, commercialization and household income indicate that growers of new improved varieties (i.e. those released after 2000) harvested 32% more than they would have obtained if they had planted local varieties. This is an equivalent of about 223 kg of additional bean harvested per hectare from plots under new improved varieties and an average of 98 kg from the actual area of about 0.44 ha under beans. The study also found that bean improvement research does propel bean commercialization in Tanzania. The average marketed surplus rose by 38% among producers that shifted their bean area from local to new improved varieties. If all households were to shift to such improved seed variety, the average effect of this transformation would be a 29% increment in marketed bean surplus, meaning that early adopters had a higher comparative advantage. An adopting household earns an additional income from bean production of about US$ 202 in PPP as net income from bean production.

The study also shows that as farmers replace old varieties or landraces with new varieties, the resulting greater yields and integration in output markets is accompanied by a growing masculinization of the value chains. For example, the marketed surplus transacted by men increase by 24.4% while that transacted by women among the same households decreased by 25%, suggesting that the control over bean sales shift from women to men.

Uganda Common Bean Crop Improvement Program

Before the TL project started its activities in Uganda in 2012, the Uganda common bean program had no structured breeding pipeline. Variety development and release were dependent on solving field production constraints. Even at that time, breeding activities within the program were conventional (pedigree and bulk breeding schemes; manual data collection) with just about 1-2 generation advancement per year and handling of less than 100 lines and populations. Only 10 crosses could be managed in a year and selection done at F5 with limited testing sites to just 3. The breeding program had no clear vision, focusing on the identified constraints. Bean production in Uganda was majorly for food security. Average farm productivity was about 0.25-0.500 t/ha. Eleven varieties were on the market (7 bush and 4 climbers). About 60-70% of seed that was planted was from own saved seed and about 30-35% was grain from the market and only about 5-10% was certified and was only accessible at Kawanda (Uganda Seed Project-MAAIF). Bean production was low and characterized by drudgery (ploughing, planting, weeding and postharvest handling and no fertilizer).

With the TL project, the Uganda common bean program started restructuring its breeding activities and adopting modern breeding techniques and approaches (MAS, pedigree selection, MABC, early generation selection and SSD) though human expertise in application of these modern tools is still limited. The program now determines its breeding schemes according to target traits captured in 6 product profiles that are guiding its national breeding strategy (*Table 41*). The program continued receiving germplasm from CIAT and other partners for evaluation under the TL project. With TL project intervention, the infrastructure has improved significantly and the program is now managing up to 75 crosses up from 10 crosses a year and populations handled increased from less than 100 in 2007 to over 1,000 by the end of TL III in 2018. Testing sites have also increased under TL projects to 9 from 3 before project intervention. The program assembled about 758 germplasm accessions with about 94.5% characterized under the TL project. The project also helped the program improve its physical infrastructure and human capacity. Three netted houses have been renovated. On the other hand, though the program has access to a molecular lab that is shared with other crops, it does not have a long-term seed storage facility and even its experimental fields are not mechanized. About 23 students have been supported by the program through TL project funding (19 MSc and 4 PhD; 11 female and 12 male). Finally, TL project intervention in the last 12 years (2007 – 2018) has enabled the Uganda common bean program to release 16 improved varieties. The program trained staff on mainstreaming gender in breeding and realigned breeding activities with gender in mind as well as in genomics and molecular breeding.

In order to increase adoption of improved common bean varieties in Uganda, the program created variety awareness through different activities like demos, field days, agri-seed fairs/exhibitions/shows, etc. About 631 demos were conducted compared to 200 that were targeted, 25 field days compared to 40 that were targeted and 26 agri-seed fairs/exhibitions/shows compared to 130 that were targeted (*Table 42*). The program established 13 MSPs compared to 4 that were targeted (325% achievement). These MSPs created conducive conditions for grain demand and variety development and especially interactions among seed systems actors. They were also used to train about 14,891 members in seed production and business management. The training curriculum included innovative marketing (e.g. small and medium seed pack), post-harvest handling and value addition, providing 15 seed companies and over 200 farmer groups nationwide with skills in quality bean seed production. Besides, to increase seed access, the SSP approach was used during TL III and 2,241 t of seed was distributed in SSPs. The program tested 4 laborsaving technologies and promoted them for uptake. They included a mobile threshing and solar bubble drier.

The program identified and engaged seed companies, CBOs, NGOs, farmer groups in production and supply of basic/foundation, certified and QDS. On average, 71 actors were involved in seed production and marketing each year (*Table 43*). A good example is the Community Enterprises Development Organization (CEDO), a membership agricultural enterprise development organization that is committed to improving agricultural production, incomes, food and nutrition security of farmers and vulnerable groups in Masaka, Rakai, Lyantonde and Sembabule districts in southwestern Uganda. It works with 15,000 households of whom 63% are women, interfacing with stakeholders at different levels, thus influencing community dynamics to deliver innovations resulting from research. The collaborative research approach involves cost sharing between CEDO, NARO and CIAT for implementation of projects in terms of materials and resources as well as the development and transfer of improved seed technologies and bean production skills among smallholder farmers. CEDO was registered as a seed company in 2010 and its bean seed production increased from about 51 tin 2010 to 296 t in 2017.

Gomba seed producers' cooperative, formerly known as Gomba seed farmer group, was established in 2006 by 25 farmers from villages in Gomba District, Central Uganda. The district receives minimal rainfall and thus the main economic activity is livestock. The group has over time grown and has registered 300 QDS producers. The common bean varieties grown by the group are NABE 2,4,15 and16. The group procures seed from National Crop Resources Research Institute (NaCRRI) which they produce individually in their farms; they can sell the seed through seed companies and NGOs. In a good season, the group collectively produces over 200 t of common beans which is marketed collectively. The group is also the main supplier of beans to schools in Gomba and Mpigi Districts. The group seeks to improve the livelihoods of community members and thus sometimes waive membership fees for members who can't afford but want to be part of the co-operative. These members are loaned seed and the amount is recovered during sale. The group distributes QDS to 90% of farmers in two sub-counties where they are based. There are several such seed producing groups on track to graduation as start-up seed companies.

Currently, breeder seed production is funded by the project. Its production capacity has increased from 1.36 t in 2012 to 21.85 t in 2018. Most of the old varieties (K131, K132, NABE1-NABE 6 etc.) have been discontinued. The same trend can be seen in foundation and certified seed production. A total of 33,776.13 t of common bean was produced in Uganda with the support of TL III, comprising of 80.54 t of breeder seed, 323.4 t of foundation seed and 33,372.19 t of certified seed. This means that the Uganda common bean program achieved 287.6% of its breeder seed target, 43.3% of its foundation seed target and 298% of its certified seed target (*Tables 35-37*).

The program was able to define the common bean market types and production hubs. Nearly 86.4% (29,070.98 t) of seed was delivered to farmers through various channels. A total of 8 seed companies were engaged in using small packages of 0.5 kg, 1 kg, 2 kg and 5 kg and about 25% of their total seed production was sold/distributed in SSP. Currently, common bean is considered a non-traditional cash crop for most families; the country was opposed to its being considered a subsistence crop in the early 2000s. There has been an increase in adoption, use and demand of new bean varieties. Productivity of common bean increased from 0.5 t/ha in 2007 to 0.7 t/ha in 2012 and 1.3 t/ha in 2018. This has further affected the country's production from 444,000 t in 2006 to over 1,000,000 t currently. The production of biofortified beans has positively impacted household gender relations and women's financial empowerment. It has created a shift in the breadwinning role towards women which is likely to narrow the empowerment gap between men and women. It has increased women's endowment through asset acquisition and enabled them to move out from the private to the public space and access resources that are not within their reach, such as hiring land.

ICRISAT Chickpea Crop Improvement Program

Before the TL Project intervention, ICRISAT had one centralized chickpea breeding program at its headquarters in Hyderabad, Patancheru, India catering to the needs of Asia and Africa. The focus country in Africa was Ethiopia. Several varieties that had been released in Ethiopia had come from ICRISAT-bred materials. With the support from TL II project, a regional chickpea breeding program for ESA started at ICRISAT-Nairobi in 2008, and in Tanzania and Ethiopia in 2013. Before the TL projects, no chickpea variety had been released in Tanzania but with the intervention of the TL project, Tanzania released 4 varieties in 2011 and facilitated their adoption. Kenya also released 7 improved varieties under TL projects.

Based on the BPAT assessment under TL III, recommendations were made to ICRISAT to develop a document that describes traits of varieties/hybrids for key TPEs. ICRISAT also developed and now works around 2 chickpea product concept notes (Product Concept Notes of GLDC Crops). The project has helped ICRISAT's India program to increase its early generation testing locations from 1 to 4 and 3 successive generations per year in the field since 2010 (2 generations at Patancheru and 1 at Hiriyur) and molecular breeding activities also. With financial support from TL and several projects funded by international and Indian agencies, ICRISAT Hq developed large scale genomic resources including genome sequencing, re-sequencing and development of markers including QTL-hotspot for drought tolerance, markers for Fusarium wilt resistance and deployed molecular breeding such as marker-assisted backcrossing, marker-assisted recurrent selection and recently genomic selection also. ICRISAT Hq has successfully developed molecular breeding lines for drought tolerance and supported chickpea breeding programs in Ethiopia, Kenya and India in use of molecular markers in chickpea breeding. Recently, ICRISAT's India chickpea program standardized protocols for taking six generations per year in a greenhouse. The program has not conducted genetic gains estimates to measure its progress. The program uses a selection intensity of about 1% in F6 and about 10% in F7 and F8.

Overall, the ICRISAT chickpea program has adopted BMS in all its breeding work and built the capacity of its NARS partners as follows:

- ICRISAT supplied about 14,000 samples of breeding materials to project partners (209 Bangladesh, 1901 Ethiopia, 9341 India, 1929 Kenya and 375 Tanzania) during 2007 to 2018.
- A total of 12 researchers from ESA (4 each from Ethiopia, Tanzania and Kenya) participated in a one-month training program at ICRISAT-Patancheru.
- Four researchers from ESA (2 each from Tanzania and Kenya) participated in a 2-week training program at ICRISAT-Patancheru.
- A total of 10 scientists from SA (5 from India and 5 from Bangladesh) participated in an Integrated Breeding multi-year course of GCP.
- A total of 3 staff from ESA were trained in electronic field books and data management at Wageningen through GCP.
- A total of 5 MSc and 6 PhD students conducted research at ICRISAT-Patancheru.

Ethiopia Chickpea Crop Improvement Program

The TL project began its chickpea activities in Ethiopia in 2007/08 at a time when the breeding program was using conventional breeding techniques and approaches (collection, characterization and selection of landraces and manual data collection). Only 15-20 crosses were being conducted annually and 1generation per year. The program had released 15 varieties derived from ICRISAT materials. Seed production and delivery was based on an informal system with annual production of about 39.5 t of foundation seed and 632.7 t of certified seed. Varietal turnover was more than 10 years while seed replacement at farm level took about 3-4 years. Adoption levels were low with average yield of 918 kg/ha and women farmers growing chickpea were very few. The program received training in genomics and molecular breeding also at CEGSB- ICRISAT Patancheru (India). Under TL III project, BPAT self-assessment was conducted in 2017 and it showed that the program was simply evaluating marker-assisted backcross (MABC) lines developed at ICRISAT for improving drought tolerance lines. In collaboration with ICRISAT, EIAR recently released one molecular breeding variety with the name of Geletu (after the name of the former pulse breeder in Ethiopia. However, integration of marker-assisted breeding is yet to be incorporated in the Ethiopian chickpea program.

Based on recommendations from the BPAT report as outlined in the PIP, TL project supported the Ethiopia chickpea program to install an irrigation facility which was very critical in enabling the programs to undertake 2 generation advancements per year as opposed to 1 before the project. This has further reduced the time it takes to release a variety from 11 years to 8 now. Laborsaving technologies (planters, thresher and combine harvester) were also introduced with the financial support of the TL III project. The program redesigned its hybridization methods besides increasing short-term and long-term trainings (MSc and PhD) to build the capacity of its staff in adopting new breeding approaches and techniques. Data collection is now digital using tablets and barcode readers and scanners acquired by TL project are now fully in use by the program. Under TL III, program researchers have been trained on BMS and currently BMS is being used for field planning, data gathering and management.

The TL III project also supported the program in conducting several activities around variety awareness and promotion (*Table 44*). A total of 2,800 demos were conducted compared to 200 that were targeted over this time period. On the other hand, 56 field days were successfully organized compared to 40 that had been planned while 3 agri-seed fairs/exhibitions/shows were conducted compared to 12 that had been targeted. The project also supported the program to establish 5 MSPs compared to the 4 that had been targeted. The MSPs were used as entry points for training stakeholders in seed production and marketing. A total of 6,429 chickpea stakeholders who were members of the MSPs were trained in good seed production and marketing practices. About 56 t of chickpea certified seed were distributed to smallholder farmers in the form of SSPs.

In order to produce enough seed of improved chickpea varieties, multiple stakeholders were used to produce both EGS and certified seed. On average, about 2 different categories of seed producers and marketers were engaged (*Table 45*). Farmer groups/organizations were the most popular category of seed producers and marketers of improved chickpea seed. During the course of the TL project, the chickpea group established and strengthened 18 seed growers associations, some of which graduated to strong seed cooperatives while others took a forward step to form seed companies. Ameha Abraham, a farmer from Adaa district in central Ethiopia had been growing improved desi and kabuli chickpea varieties since 1995. In 2009, he and his colleagues were supported through TL II project to form a seed producers' association with 119 member farmers. Ameha and other farmers started by selling seeds individually to seed producers' associations. In 2012, Ameha and a fraction of the association members set up a private seed company – Amuari High Yielding Varieties & Agricultural Products PLC. The initial funding of ETB 100,000 (US$ 5000) was in the form of share capital of ETB 10,000 each from 10 founding members. There are 18 such seed growers associations in Ethiopia graduating into private companies with more diversified crop portfolios.

TL interventions have assisted the program in adopting modern breeding techniques (MAS, MABC and MARS) and approaches (product profiles). The breeding pipeline has also been modified to manage 81 crosses per year as opposed to 24 crosses per year in 2007 before the TL project. Four product profiles have been developed to guide the Ethiopia chickpea breeding program: Early-maturing, drought- and heat-tolerant breeding lines; Fusarium wilt and Ascochyta blight resistance; Herbicide/or suitability to mechanical harvesting; and Lines with better cooking quality. Finally, for the last 12 years of TL investments in Ethiopia, the program has released 13 varieties, 2 of them suitable for mechanical harvesting – a big achievement towards reducing women's drudgery (*Table 5*). A genetic progress in seed yield and yield related characters of 10 kabuli chickpea varieties released by the Ethiopian Chickpea Crop Improvement Program from 1974 to 2017 was assessed during the main cropping season. The overall increase in seed yield over the local check, DZ-10-4, was estimated to be 739 kg/ha (38.9%). On station grain yield increased from 1900 to 3250 kg/ha during the last 43 years and the overall increase in seed yield of the Arerti variety over the oldest variety DZ-10-4 was estimated to be 1350 kg/ha or 71.1%. Based on the regression analysis, the estimated average annual rate of increase in grain yield potential was 10.87kg/ha/year with an annual relative genetic change of 0.57%/year.

Involving multiple categories of stakeholders in production and marketing of improved chickpea seed enabled the program to produce about 14,478 t of improved chickpea seed. This constituted 34.26 t of breeder seed, 2,156 t of foundation seed and 12,287.74 t of certified seed (*Tables 46-48*). More women and youth are now involved in chickpea production than before and productivity is currently about 2 t/ha compared to less than 1 t/ha before project interventions. TL III supported the program in developing machine-harvestable varieties and mechanization of cultivation and harvesting processes. The scale of mechanized operations in chickpea cropping systems is expanding in the wheat belt of Ethiopia.

India Chickpea Crop Improvement Program

During the TL project, the India chickpea program (Indian Institute of Pulses Research) focused on breeding for four major traits: (1) Early-maturing, drought and heat tolerant breeding lines; (2) Fusarium wilt and Ascochyta blight resistance; (3) Herbicide/or suitability to mechanical harvesting; and (4) Lines with better cooking quality. These traits reflect the 4 product profiles for the India chickpea program, and they are revised periodically based on the changing scenario of chickpea cultivation and market demand.

Under TL III, a BPAT self-assessment identified key areas in the India chickpea program that needed to be addressed in order improve program efficiency and effectiveness. Though the program had no major problem with physical facilities, human capacity needed to be improved. The program was supported by the project to digitalize its historical breeding data (pedigree of breeding lines in different generations) and field trial data by providing training, interactive sessions, lectures and hands-on workshops. This has enabled the program to use BMS for field planning, data gathering and management.

Several technology awareness and promotional activities were conducted to increase awareness among stakeholders about improved chickpea varieties. A total of 214 demos were established by the program compared to 80 demos that were targeted, 7 field days conducted compared to 20 targeted and 3 agri-seed fairs/shows/exhibitions held (*Table 49*). The program also successfully conducted 102 FPVS against a target of 10. The project supported the program to establish 11 MSPs against the target of 4 and trained about 3,080 members in good seed production and marketing practices. A total of 348 t of improved chickpea seed was distributed o farmers in SSPs since TL III inception in 2015. The India chickpea program mainly engaged farmer organizations/groups and NGOs to produce EGS and certified seed.

The TL projects have supported the Indian institute of Pulses Research (IIPR) in managing 2 generations per year (1 in the main season at ICRISAT and 1 in the off-season at Dharwad). A modified pedigree method is also currently being used to advance the generations. Selection in early segregating generations (F2, F3) are made for simply inherited traits (maturity, plant height, plant type, seed traits, etc.) and the selected plants are bulked. The project has supported the program to use molecular markers for introgression "QTL-hotspot" for drought tolerance in elite variety. In fact, with support from TL projects and some other related projects from Generation Challenge Program and Government of India, Indian Agricultural Research Institute (IARI) and University of Agricultural Sciences- Dharwad developed and released Pusa Chickpea 10216 (BGM 10216) for drought tolerance and MABC-WR-SA-1 resistant for Fusarium wilt developed through molecular breeding in India. Finally, during the TL projects (2007 – 2008), a total of 4 varieties were released (IPC 2006-77, IPC 2004-98, IPC 2005-62 and IPC 2004-01) while 29 are still under evaluation (11 in other parts of India while 18 are under the State of Uttar Pradesh). In terms of seed production, 216.02 t of chickpea seed was produced by the program with the support of the project, comprising of 50.54 t of breeder seed, 24.29 t of foundation seed and 141.19 t of certified seed (*Tables 46-48*).

6.0 PROJECT MANAGEMENT COORDINATION

- The project revised the MLE framework, indicators and MLE data collection tools developed in 2016 and used it for planning, monitoring, planning, evaluation, accountability, learning and implementation in 2017. The project also trained partners on the digital MLE tool (http://measure.icrisat.org) that enabled real time data collection in the field, aggregation and reporting. The MEASURE team also captured the activities, outputs and outcomes of Tropical Legumes Projects over the years (http://52.40.207.123/country_crop_data/all_data.html)
- For monitoring purposes, the monitoring team visited all the partners, working with partners in refining their workplans, rolling out their program improvement plans, and implementing their product profiles as defined in the 2017 Annual Review and Planning Meeting.

The PI, Dr Rajeev Varshney visited West African countries (Burkina Faso, Ghana, Nigeria, and Niger) with seed systems specialists and the regional coordinator.

- TL III developed the digital seed catalogue (http://seedsystems.icrisat.org) linked to seed production planning and adoption roadmap (http://seedroadmap.icrisat.org). The digital seed catalogue tool has elicited interest among several non-project partners, including ICARDA, IITA, ISSD, CORAF, CIMMYT, TASAI, several seed companies and national programs. Currently, the tool is undergoing a modification to include maize. Director of CSIR-Ghana and CORAF have asked that the tool be modified to include all ECOWAS varieties in the catalogue to enhance seed production planning.
- The findings of BPAT assessments (Monyo.Country Breeding Program Assessments-final) and recommendations for improvement (Monyo. Country Progress on PIP's Details-final; IITA Nigeria PIP; CIAT Uganda breeding program) formed the basis of a number of activities currently being implemented by the programs under AVISA project.
- For sustainable legume production, it is not enough to generate new high yielding market preferred varieties and seed production, but instead it is equally important to have well trained next generation of breeders. With this objective, TL projects have managed to train 34 Masters degree and 18 PhD degree students including 10 females and 42 males.
- The TL III End of Project Workshop was held in Arusha, Tanzania from 16-18 July 2019 to: (i) review outcomes of the 12 years of the Tropical Legumes Projects; (ii) plan for the roll-over of TL III into AVISA; and (iii) further fine-tune TL III exit plans. During the workshop, partners made presentations highlighting TL III progress by program (https://cgiar-my.sharepoint.com/:f:/g/personal/r_gekanana_cgiar_org/Eix7cxrGyyJDlPIE1xzmnK4B3F_cl1QGB61ia46k5ZiP1A?e=piQqWi) starting from the baseline in 2007, activities done, outputs and outcomes and the current status of the programs.
- A total of 21 articles (TL III Voices & Lessons_Featured Stories) were disseminated through ICRISAT Happenings newsletter and TL III website between 1 May 2018 and 30 Sep 2019. The details are available on the TL III website http://tropicallegumes.icrisat.org/newsblogs/.
- Project outputs were disseminated through a special issue (https://onlinelibrary.wiley.com/doi/abs/10.1111/pbr.12632) in the journal Plant Breeding with 10 peer-reviewed articles highlighting 12 years (2007–2019) of research, achievements, lessons learned, challenges and gaps in discovery-to-delivery research in legumes emanating from three projects, collectively called Tropical Legumes (TL) Projects funded by the Bill & Melinda Gates Foundation.
- Information on the project activities is regularly shared through social media channels: LinkedIn: https://www.linkedin.com/groups/7039014/?msgConversationId=6320815379241410560&msgOverlay=true; https://www.facebook.com/tropicallegumesIII/; Twitter: https://twitter.com/tropicallegumes; Flickr: https://www.flickr.com/photos/tropicallegumes/ ; YouTube: https://www.youtube.com/channel/UCFi3qGwZoYX5jJkvuvH_o7w

CHALLENGES

Ongoing insecurity and/or instability in some of our target countries (Northern Nigeria, Ethiopia, Burkina Faso and Mali) remain an issue of concern. Besides, there were procurement challenges with NARS partners. It normally takes too long to make purchases. We overcame this by procuring equipment for the NARS and back-charging their budgets where they consented. In some instances, there were challenges in sending funds to regional centers (e.g. Ethiopia) or in purchasing flight tickets (e.g. India), to the extent that the respective CGIAR partner bailed them out and requested deduction of the amount at the time of sending the funds to NARS. This may call for a rethink on resource allocation to some partners. The greatest challenge was with regard to adoption studies backstopped with fingerprinting. Partners handled the process separately, but in all cases, the process was not smooth and the results were not forthcoming. To date, partners are yet to produce fingerprinting-supported adoption reports.

2. Geographic Areas to Be Served

Provide the final list of countries and sub-regions/states that have benefitted from this work and associated dollar amounts. If areas to be served include the United States, indicate city and state. Add more rows as needed. More information about Geographic Areas to Be Served can be found here**.**

Location	Foundation Funding (U.S.$)

3. Geographic Location of Work

Provide the final list of countries and sub-regions/states where this work has been performed and associated dollar amounts. If location of work includes the United States, indicate city and state. Add more rows as needed. More information about Geographic Location of Work can be found here.

Location	Foundation Funding (U.S.$)

4. Lessons Learned

Describe the top one to three takeaways or lessons learned from this project.

1. In order to create impacts with investments around crop improvement and seed delivery, it is important that the governments co-invest in research and development especially in the supply of early generation seed
2. There is a need to pay some attention to the pull factors of new varieties post farm operations, such as grain aggregation, processing and value addition. This helps to create and sustain demand for high quality seed of target varieties.
3. The CGIAR-NARS partnership should not be based on time-bound projects only. There should be a sustainable relationship like the one running under Pan-African Bean Research Alliance (PABRA).

5. Feedback for the Foundation

Provide one to three ways the foundation successfully enabled your work during this project. Provide one to three ways the foundation can improve.

Ways the foundation has successfully enabled your work

- The foundation has created a collaborative atmosphere for easy exchange of ideas. The program officer has guided the implementation of the project very closely.

Ways the foundation can improve

- Support to leadership training and team building activities not budgeted for in the project such as Mythodrama Convening

6. Global Access and Intellectual Property

If your funding agreement is subject to Intellectual Property Reporting, please click the following link to complete an Intellectual Property (IP) Report.

If not, please acknowledge by typing "N/A": Submitted as a separate document.

To delegate permissions to another member of your project team or for any questions regarding the Intellectual Property Report, please contact GlobalAccess@gatesfoundation.org.

7. Regulated Activities

Do you represent that all Regulated Activities[1] related to your project are in compliance with all applicable safety, regulatory, ethical and legal requirements? Please mark with an "X":

______ N/A (no Regulated Activities in project)

_X___ Yes

_____ No (if no, please explain below)

1 Regulated Activities include but are not limited to: clinical trials; research involving human subjects; provision of diagnostic, prophylactic, medical or health services; experimental medicine; the use of human tissue, animals, radioactive isotopes, pathogenic organisms, genetically modified organisms, recombinant nucleic acids, Select Agents or Toxins (www.selectagents.gov), Dual Use technology (http://export.gov/regulation/eg_main_018229.asp), or any substance, organism, or material that is toxic or hazardous; as well as the approvals, records, data, specimens, and materials related to any of the forgoing.

8. Subgrants

If your grant agreement (not applicable to contracts) is subject to expenditure responsibility and permits you to make subgrants to organizations that are not U.S. public charities or government agencies/instrumentalities, please complete the Subgrantee Checklist and attach a copy with this progress narrative for each such subgrantee.

Financial Update

The purpose of this section is to help the foundation understand how programmatic performance affects actual expenditures over the life of the investment.

Feel free to reach out to your foundation contact for support with these progress reporting requirements.

Note: Budget template and financial narrative instructions can be found here. If you are using an older version of the budget template, this information could be in a different location in your template.

1. Latest Period Variance:

"Latest period variance" compares expenditures that occurred in the reporting period against the most recent forecast. See "Financial Summary & Reporting" sheet in the foundation budget template for calculated variance (for example, column AD, starting on row 29 for period 1). Note that the allowable variance is defined in your grant agreement.

1. Sub-awards (if applicable)

This sub-award section provides visibility to an often critical component of the grant spending where the budget template provides limited insight. The total of actual disbursements for this reporting period should equal the actual sub-award expenses reported on the "Financial Summary & Reporting" sheet in the budget template for this reporting period.

Use the table below to provide the detail of all sub-grantee(s) or subcontractor(s).

For sub-awards greater than $1M, please provide explanatory detail as requested in the latest and future period sections above.

Note: It is the foundation's discretion to ask for updated sub-award budget files as part of the traditional progress report review process.

2. Other Sources of Support (if applicable):

Other Sources of Support include interest earned, current foreign exchange impacts, and co-funding (in-kind and other contributions).

Checklist - As you review your answers to questions in the financial update section, ensure that your report provides the following:

1. Explanation of how project expenditures differed from plan and the implications on programmatic progress to date.
2. Explanation of how future period projections differ from the original budget and previous forecasts, and the implications.
3. Explanation of other sources of support (funds) from other funders, interest earned or converting to non-USD currencies.

Privacy and Non-Confidentiality Notice

For Foundation Staff to Complete

Analysis (required if PO assessment differs from grantee/vendor assessment or if there are unexpended funds)

Progress Analysis

Include analysis of significant project variances and key learnings that may inform portfolio discussions for progress against the strategic goals.

Budget and Financial Analysis

Include analysis of unexpended funds or over expenditures. Refer to the Unexpended Grant Funds Policy for options available when recommending how to handle unexpended grant funds, or reach out to your primary contact in GCM.