FY 2017 TECHNICAL PROGRESS REPORTS

October 1, 2016–September 30, 2017

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (Legume Innovation Lab)

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This publication was made possible through support provided by the United States Agency for International Development (USAID), as part of Feed the Future, the U.S. Government's global hunger and food security initiative, under the terms of Cooperative Agreement No. EDH-A-00-07-00005-00. The opinions expressed herein are those of the Legume Innovation Lab and do not necessarily reflect the views of USAID or the U.S. Government.

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Abbreviations and Acronyms

AOR	Agreement Officer's Representative, USAID
ARS	Agricultural Research Service (USDA)
BCMNV	Bean Common Mosaic Necrosis Virus
BCMV	Bean Common Mosaic Virus
BIC	Bean Improvement Cooperative
BGYMV	Bean Golden Yellow Mosaic Virus
BHEARD	Borlaug Higher Education for Agricultural Research and Development Program
BNF	Biological Nitrogen Fixation
Bt	*Bacillus thuringiensis*
CA	Central America (Includes Guatemala, Honduras, El Salvador, Nicaragua and Costa Rica)
CCARDESA	Centre for Coordination of Agricultural Research and Development for Southern Africa
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
CRI	Crops Research Institute (Kumasi, Ghana)
CRP	Consortium Research Program
CRSP	Collaborative Research Support Program
CSB	Community Seed Bank
CSD	Community Seed Depot (MASFRIJOL)- equivalent to CSB
CSIR	Council for Scientific and Industrial Research (Ghana)
DDL	Development Data Library
DEC	Development Experience Clearinghouse
DEPI	Dynamic Environmental Phenotyping Imager
EAP	Escuela Agrícola Panamericana–Zamorano (Honduras)
EET	USAID commissioned External Evaluation Team
FAO	Food and Agriculture Organization
FTF	Feed the Future
GWAS	Genome-Wide Association Study
HC	Host Country
IARC	International Agriculture Research Center (of the CGIAR)
ICM	Integrated Crop Management
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics

ICTA	Instituto de Ciencia y Tecnologia Agrícolas (Guatemala)
IIAM	Instituto de Investigação Agrária de Moçambique (Mozambique)
IITA	International Institute of Tropical Agriculture
INERA	Institut de l'Environnement et de Recherches Agricoles (Burkina Faso)
INRAN	Institut National de la Recherche Agronomique du Niger (Niger)
INTA	Instituto Nacional de Tecnologías Agrícolas (Nicaragua)
IPM-omics	Integrated Pest Management-omics
ISRA	Institut Sénégalais de Recherches Agricoles (Senegal)
IYP	International Year of Pulses
KSU	Kansas State University
LIL	Feed the Future Innovation Lab for Collaborative Research on Grain Legumes
LSP	Legume Scholars Program
LUANAR	Lilongwe University of Agriculture and Natural Resources
MAS	Marker-Assisted Selection
ME	Management Entity for the Legume Innovation Lab (Michigan State University)
MO	Management Office of the Legume Innovation Lab
MSU	Michigan State University
MSPAS	Ministerio de Salud Pública y Asistencia Social, Guatemala
NaCRRI	National Crops Resources Research Institute (Uganda)
NARS	National Agriculture Research System(s)
NGOs	Nongovernmental Organizations
NSS	National Seed Service (Haiti)
PABRA	Pan-African Bean Research Alliance
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales
PI	Principal Investigator
QDS	Quality Declared Seed
QTL	Quantitative trait loci
RIL	Recombinant Inbred Lines
RMC	Research Management Committee
RFP	Request for Proposals
SABREN	Southern African Bean Research Network
SARI	Savannah Agriculture Research Institute (Tamale, Ghana)
SNF	Symbiotic Nitrogen Fixation
SNP	Single Nucleotide Polymorphism

SO	Strategic Objective
SUA	Sokoine University of Agriculture (Morogoro, Tanzania)
TMAC	Technical Management Advisory Committee
UCR	University of California- Riverside
UNZA	University of Zambia
UNL	University of Nebraska- Lincoln
UPR	University of Puerto Rico
USDA	United States Department of Agriculture
ZARI	Zambian Agriculture Research Institute (Zambia)

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Host Countries and Legume Innovation Lab Projects

West Africa

- Benin (SO1.B1),
- Burkina Faso (SO1.A5 and SO1.B1)
- Ghana (SO1.A5 and SO1.B1)
- Niger (SO1.B1)
- Senegal (SO1.A5)

East and Southern Africa

- Malawi (SO2.2 and SO3.1)
- Mozambique (SO2.1)
- Tanzania (SO2.2 and SO4.1)
- Uganda (SO1.A3 and SO2.1)
- Zambia (SO1.A2, SO1.A3 and SO2.2)

Latin America and the Caribbean

- Guatemala (SO1.A1, SO1.A4 and MasFrijol)
- Haiti (SO1.A4)
- Honduras (SO1.A4)

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- University of Hawaii University of Nebraska
- USDA/ARS, Michigan State University USDA/ARS, Prosser, Washington
- USDA/ARS, Tropical Agriculture Research Station, Mayaguez, Puerto Rico

Subcontracted International Institutions

Benin	International Institute of Tropical Agriculture (IITA–Benin)
Burkina Faso	Institut de l'Environnement et de Recherches Agrícolas (INERA)
Ghana	Crops Research Institute (CRI)
	Savanna Agricultural Research Institute (SARI)
Guatemala	Instituto de Ciencia y Tecnología Agrícolas (ICTA)
	Fundación para la Innovación Tecnológica, Agropecuaria y Forestal (FUNDIT)
	Ministerio de Salud Pública de Guatemala (MSPAS)
	Centro de Comunicación para el Desarrollo (CECODE)
Haiti	National Seed Service (NSS), Ministry of Agriculture
Honduras	Escuela Agrícola Panamericana–Zamorano (EAP–Zamorano) and
	Dirección de Ciencia y Tecnología (DICTA)
Malawi	Lilongwe University of Agriculture and Natural Resources (LUANAR)
	University of Malawi College of Medicine, Malawi
Mozambique	Instituto de Investigação Agrária de Moçambique (IIAM)
Nicaragua	Instituto Nicaragüense de Tecnologías Agrícolas (INTA)
Niger	Institut National de la Recherche Agronomique du Niger (INRAN)
Senegal	Institut Sénégalais de Recherches Agricoles (ISRA)
Tanzania	Sokoine University of Agriculture (SUA)
Uganda	Makerere University
	National Agricultural Research Laboratories (NARL)
	National Crops Resources Research Institute (NaCRRI)
Zambia	Zambia Agriculture Research Institute (ZARI)
	University of Zambia (UNZA)

I. LIL Executive Summary

The Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (Legume Innovation Lab, LIL), 2013–2017, supports research and institutional capacity strengthening projects to (1) enhance grain legume productivity through genetic improvement and integrated pest management, (2) improve smallholder farmer decision making regarding sustainable soil fertility management in legume–cereal cropping systems, (3) strengthen legume value-chain performance, and to (4) improve human nutrition and health through increased consumption of grain legumes. Serving as the Management Entity, Michigan State University subcontracts ten multi-institutional, multi-country and multidisciplinary projects with U.S. universities which in turn sub-subcontract collaborative research and institutional capacity strengthening activities with agriculture research institutions (NARS, agriculture universities) in 11 Feed the Future focus countries in West Africa, Eastern and Southern Africa, and Central America and Haiti. LIL research projects focus primarily on common bean and cowpea because of their strategic importance to the food and nutritional security of rural poor in these regions. As an extension of the Dry Grain Pulses CRSP (2007–2012), LIL is a mature program with a relatively full research pipeline of technological solutions (e.g., improved climate-resilient and disease resistance bean and cowpea varieties; sustainable integrated pest management practices using biologicals to control insect pests in cowpea; communications tools for low education farmers) and new knowledge (e.g., factors influencing farmer soil fertility management decision making, attributes of sustainable of seed systems for legumes, nutritional and health benefits of grain legumes in diets of young children, function of grain legume value chains) that can benefit stakeholders of grain legume value chains in developing countries.

A 10-member Technical Management Advisory Committee (TMAC) monitored the technical progress of subcontracted LIL projects through the evaluation of annual workplans, budgets and technical progress reports as well as advised both the Management Office and USAID on all technical and administrative matters regarding program implementation and performance. The TMAC also conducted periodic visits to project sites.

The Legume Innovation Lab, in partnership with INERA-Burkina Faso, hosted the 2017 LIL Grain Legume Research Conference on August 13-19, 2017 at the Laico Ouaga 2000 Hotel in Ouagadougou, Burkina Faso. Attended by approximately 140 grain legume scientists and graduate students, the conference highlighted the research achievements and the developmental outcomes in the bean and cowpea sectors in SubSaharan Africa and Central America and Haiti resulting from investments by the LIL program.

As a response to the food insecurity situation in Haiti following Hurricane Matthew in October 2016, the USAID Mission to Haiti provided $1,982,841 to the Legume Innovation Lab Management Office at Michigan State University to implement a bean seed security relief project in Haiti, *Mwen Gen Pwa*. Since the performance period of this one year project was 11/1/2016 to 11/30/2017, the end date of the Legume Innovation Lab award was extended until 11/30/2017.

In FY 2017 the Management Office of LIL continued to administer the MASFRIJOL (2014–2018) associate award (AID-OAA-LA-14-00005) contracted by the USAID Guatemala Mission. In addition, the Bureau of Food Security, USAID/Washington contracted a second associate award to the LIL Leader Award for the Legume Scholars Program (AID-OAA-LA-17-00002) for the performance period 04/01/2017 to 09/30/2019 with total funding of $750,000.

Specific information on LIL program management, activities, and projects and achievements can be found on the program’s webpage, legumelab.msu.edu.

II. LIL Program Activities and Highlights

FY 2017 was the fifth and final year of the Feed the Future Innovation Lab for Collaborative Research Program on Grain Legumes (Legume Innovation Lab) administered by Michigan State University (AID-EDH-A-00-07-00005). Through modification 12, signed on June 22, 2017, the estimated completion date for the agreement was extended from September 29, 2017 to November 30, 2017. The primary justification for the no-cost extension was to enable completion of the Mwen Gen Pwa Haiti Bean Seed Relief Project, a buy-in by the USAID Mission to Haiti. The extension also enabled certain subcontracted LIL projects to fully complete their research and training commitments so as to better achieve the objectives identified in the FY 2017 LIL Project Workplans.

The Management Office (MO) is pleased to report that FY 2017 was a highly productive and successful year. All ten subcontracted research and institutional strengthening/training projects made extraordinary technical gains. Several projects reporting research outputs that will clearly have impact on the grain legume sectors and stakeholders in both Feed the Future countries and the United States. A summary of financial obligations to subcontracted projects is presented in Appendix A, Table 4.

The highlight of the year was the LIL Grain Legume Research Conference in Ouagadougou, Burkina Faso, on 13-18 August 2017. This conference was held in partnership with the Institut de l'Environnement et des Recherches Agricoles (INERA) of Burkina Faso. Approximately 140 African, Latin American and U.S. scientists and graduate students affiliated with the Legume Innovation Lab presented their grain legume research findings, technical achievements and development outcomes during the conference. CGIAR colleagues were able to participate as well as key USAID Mission staff members from the region and Burkina Faso government ministers and other officials.

The Mwen Gen Pwa Haiti Bean Seed Relief Project, a buy-in from the USAID-Haiti Mission, distributed 206 MT of high quality certified black-bean seed (Zenith, Zorro, ICTA Ligero, DCP-40) to 11,447 households in the Departments of Sud and Grand-Anse affected by Hurricane Matthew in Haiti.

LIL PIs, Drs. James Beaver (University of Puerto Rico) and Juan Carlos Rosas (EAP-Zamorano, Honduras) received the 2017 BIFAD award for Scientific Excellence in a Feed the Future Innovation Lab. The team is responsible for the breeding and release of >60 high yielding, adapted, disease resistant bean cultivars with desired grain quality attributes that are being grown throughout six countries in Central America and the Caribbean.

The MASFRIJOL project, an associate award under the LIL leader, reached an additional 3,457 beneficiary families in FY17 with quality seed of improved high yielding black bean varieties adapted to the Western highlands of Guatemala. Since the inception of the project, >35,000 households have received seed and technical assistance. A total of 96 Community Seed Depots (CSD) comprised of smallholder Mayan farmers have been established by MASFRIJOL. During the past year, the CSDs produced nearly 9 MT of seed which was sold to local farmers as a profit generating enterprise. Approximately 22,800 persons attended at least one nutritional education class in FY 2017 which promotes nutrient-rich bean consumption as a complement to other locally produced foods in diets.

The Bureau of Food Security, USAID/Washington, contracted a second associate award to the LIL

Leader Award for the Legume Scholars Program (AID-OAA-LA-17-00002) for the performance period 04/01/2017 through 09/30/2019; total estimated award amount $750,000.

III. LIL Key Accomplishments

SO1.A1. Genomic analysis revealed that the Guatemalan climbing bean accessions from the Western highlands represent a distinct new race of Mesoamerican bean, 'Race Guatemala'. This germplasm will be a valuable new source of genes for traits important to the breeding of improved common bean varieties.

SO1.A2. QTLs for drought tolerance were identified in common bean in Zambia utilizing the MultispeQ and PhotosynQ systems to measure photosynthetic parameters under varying water deficit regimes. Leaf cooling through transpiration was demonstrated as being important for heat tolerance and the function of photosynthetic processes in common bean under high temperatures. Breeding for heat tolerance in bean should include phenotyping and selection of lines with associated traits (e.g., stomatal conductance, etc.).

SO1.A3. Nutritionally superior common bean genotypes of farmer-preferred market classes (red-mottled and yellow) exhibiting adaptation to Ugandan bean production regions were identified.

SO1.A4. A genetic marker for resistance to common bean weevil, *Acanthoscelides obtectus*, a major grain storage pest in Africa and Latin America, has been identified in common bean. These markers will accelerate the breeding of weevil resistant varieties. Novel QTLs for resistance to angular leaf spot and halo bacterial blight have been identified in Mesoamerican bean lines. The first tepary (*Phaseolus accutifolius*) bean breeding lines with tolerance to BGYMV were developed and novel sources of resistance to BCMNV and web blight identified for future introgression. A newly developed BGYMV resistant determinant black bean variety adapted to the tropical lowlands, 'Patriarca', was released by ICTA in Guatemala. A new black bean variety with multiple virus resistances and drought tolerance, 'Lenca Precóz', was released in Honduras.

SO1.A5. A differential cowpea panel was used to identify several aphid resistance sources effective against both U.S. and West African aphid populations. Three aphid resistance loci were genetically mapped to three different cowpea chromosomes. Advanced backcross progenies were developed by adding aphid resistance QTLs into elite recurrent parent varieties for African and U.S. cowpea production

SO1.B1. A total of 101,600 adult parasitoids of two species*, Phanerotoma syleptae* and *Therophilus javanus*, were released in Burkina Faso and Benin with the participation of local communities. These parasitoids have become naturalized and are projected to contribute to the biological control for cowpea pod borer (*Maruca vitrata*).

SO2.1. Farmers in Uganda effectively distinguished and mapped five local soil types utilizing observable soil characteristics (color, texture, stoniness, etc.), important information for assessing soil fertility attributes and appropriateness of soils for grain legume crop production. Mobile apps developed by IIAM-Mozambique for use on smartphones were shown to be highly effective in reaching smallholder farmers, especially women, with science based information on bean production and a valuable educational tool for extension officers.

SO3.1. The addition of cowpea (4.6-5.2 g protein/day and 4-5 g/day of indigestible carbohydrate) to complementary feeding of Malawian infants (6 to 12 mo of age) resulted in less linear growth faltering (reduced stunting). The addition of common bean to complementary feeding of rural Malawian children (12-23 months) led to an improvement in biomarkers of gut health, although this did not directly translate in improved linear growth of infants. Food metabolite analyses identified potential dietary biomarkers of legume intake for stool, urine and blood detection that could be used to assess the relationship between distinct legume consumed and health outcomes.

SO4.1. A study based of 8,000 small rural farm households in Zambia indicate positive effects of cereal-legume rotation and other legume technologies on net crop income, calorie and protein production, and months of adequate household food provisioning. A study on farmer willingness to pay for quality seed in Tanzania (for beans) and Ghana (for cowpeas) found that seed quality matters; certified seed out-performs QDS and QDS outperforms farmer recycled seed. Farmers are also willing to pay a premium for quality seed—but are influenced by their perception of seed quality differences.

IV. LIL Research Program Overview and Structure

The Legume Innovation Lab focuses its research and institutional capacity strengthening efforts on four Strategic Objectives (SOs) in the 4.5-year extension (2013–2017).

Strategic Objective 1. <u>Advancing the Productivity Frontier</u>: To substantively and sustainably increase grain legume productivity by improving adaptation to diverse agro-ecologies and reducing smallholder farmer vulnerability to climate change, with special consideration for the livelihoods of women.

- **SO1.A:** To substantively enhance the genetic yield potential of grain legumes by exploiting new research tools afforded by genomics and molecular breeding approaches (e.g., MAS), with a focus on improving resistances to economically important abiotic and biotic constraints that limit yield in the agro-ecological regions where legumes are commonly grown in Africa and Latin America
- **SO1.B:** To sustainably reduce the yield gap for selected grain legume crops produced by smallholder, resource-poor farmers in strategic cropping systems

Strategic Objective 2. <u>Transforming Grain Legume Systems and Value Chains</u>: To transform grain legume-based systems through improved smallholder production management decision making and more effectual governance management of grain legume value chains by stakeholders

Strategic Objective 3. <u>Enhancing Nutrition</u>: To improve the nutritional quality of diets and to enhance the nutritional and health status of the poor, especially women and young children, through the consumption of edible grain legume-based foods

Strategic Objective 4. <u>Improving Outcomes of Research and Capacity Building</u>: To improve outcomes of legume research and capacity building projects and to assess impacts to improve future decisions

In 2017, Michigan State University administered a portfolio of ten subcontracted multi-institutional collaborative research and capacity strengthening projects, a Bean Seed Security Project in Haiti, and one associate award (MASFRIJOL) in Guatemala. A lead PI at a subcontracted U.S. university is responsible for the development of annual workplans and budgets, project implementation, monitoring of technical progress, and annual reporting for each project.

The Legume Innovation Lab's technical approach for FY 2013–2017 contributes to USAID's Feed the Future goals and research strategy for grain legumes by:

- Contributing directly to the FTF themes of: (1) Advancing the Productivity Frontier, (2) Transforming Key Production Systems, and (3) Enhancing Nutrition and Food Safety;
- Assuming a leadership role within the international grain legume research community through engagement of leading scientists at U.S. universities and advanced HC research institutions, and coordination with CGIAR legume scientists through the CG's Research Program on Grain Legumes;
- Focusing on priority FTF focus countries and cropping systems (the West African Sudano–Sahelian systems, the Eastern and Southern African maize-based systems, and the maize–bean cropping system in Central America);
- Supporting USAID's whole-of-government approach through coordination with USDA/ARS FTF scientists;
- Enhancing the capacity of strategic national and international agriculture research institutions to address critical needs so as to be able to respond to future challenges of the grain legume sectors;

- Advancing gender equity through research, technology dissemination, and capacity building activities that directly benefit women;
- Achieving broad, quantifiable, sustainable impacts from outputs of Legume Innovation Lab research as evidenced by widespread technology adoption and benefits to stakeholders of legume value chains—from smallholder farmers to consumers of grain legumes; and
- Supporting USAID country and regional mission FTF strategic value chains and agriculture sector development priorities.

Genetic Improvement of Middle-American Climbing Beans for Guatemala (SO1.A1)

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I. Abstract of Research and Capacity Strengthening Achievements

The final year of this project allowed the completion of multiple research efforts initiated at the beginning of this cycle. The most impactful accomplishment of this project is the release of two new climbing bean varieties (ICTA-Labor Ovalle and ICTA-Utatlan), adapted to the conditions of the highlands in Guatemala and the Milpa intercropping system, which is the most common cropping method in the region. With the help of partner projects such as Buena Milpa and MASFRIJOL, at least 7500 lbs of each variety were distributed to growers during FY2017 and they are being currently grown in farmer's field during the 2017 growing season. Studies focused on the molecular characterization of the genetic diversity of the ICTA germplasm collection and a new collection obtained through a grower's survey, allowed a better understanding of the organization of the genetic diversity. Results have shown that this Guatemalan germplasm is very unique and distinct from the rest of genetic material from Central America, suggesting a separate genetic race. This confirms something that has been suggested before based on results using a handful of Guatemalan climbing beans, but the scale and resolution done in this project allows to be sure of this genetic distribution. These results may change the way in which the organization of bean genetic diversity from Central America will be presented in future papers. The identification of pathogenic races of bean rust and anthracnose in Guatemala is another big accomplishment because it will allow to design effective breeding strategies for genetic resistance to these pathogens by combining the most appropriate genes for durable resistance. A total of six and three races of anthracnose and rust were found, respectivele. Screening of the ICTA climbing bean collection with some of these races as well as races of economic importance in the US, allowed the identification of new potential sources of resistance to both diseases that will be useful not only in Guatemala but in elsewhere. In addition, genetic mapping studies are helping to understand if resistance is controlled by genes already known/reported, or if new genes are being identified. Results showed that some genes appear to be in genomic locations previously reported but some other genomic regions are completely new. Finally, three students have completed their M.S. degrees and are returning to their home countries to apply all the concepts and training received at NDSU. This is a very important capacity building accomplishment. Their research was shared at multiple scientific conferences and collectively, allowed them win four awards for either best poster or oral presentations at these conferences. This is a testimony of the high quality of these students and the research and training they received.

II. Project Problem Statement and Justification

With approximately 11 million habitants, Guatemala is mostly a rural country, with 60% of the population living in farms and 50% of the population being indigenous. Maize and beans are the main staple food in most households with a per capita bean consumption of 9.4 kg per year. Since few other sources of protein are available, this amount is not enough to ensure an acceptable nutritional quality, especially within poor households. As expected, the lack of protein intake has reduced the nutritional quality in many households, significantly affecting children. Chronic malnutrition is frequent among children under 5 years old in the western highlands, with 67% of children affected, making Guatemala the country with the highest malnutrition level in the western hemisphere. One out of every three children from ages six to 59 months in the western highlands shows some degree of anemia. Approximately 18% of reproductive-age women exhibit anemia, with 29% prevalence among pregnant women and 23% prevalence among breastfeeding women.

Beans are grown on 31% of the agricultural land and mostly in the low to mid-altitude regions (0-1500 masl) in a monoculture system. Contrastingly, intercropping (locally known as Milpa) is the main production system in the highlands, where maize-bean is the most common crop association. Unfortunately, on-farm productivity of these climbing beans is approximately one third of their genetic yield potential mostly due to the lack of improved cultivars that are able to withstand biotic and abiotic stresses. Fungal and bacterial diseases as well as pests are the main cause for yield reductions. In addition, production is made with almost no inputs of fertilizers and/or other chemicals. Historically, climbing beans worldwide have received less attention and breeding efforts in comparison with the bush-type beans commonly grown in the lowlands, as shown by the significant yield gap between regions. In addition, there are genetic and environmental interactions among species (maize, bean, squash, etc.) not well understood within the intercropping system that may affect crop performance and hence, seed yield. The legume Innovation Lab has been involved in collaborative bean breeding research targeting lowland agro-ecologies in Central America, but research for the highland bean production systems is still lacking.

There is an existing collection of approximately 600 accessions of climbing beans collected across all bean production regions in Guatemala. This collection is kept by ICTA and has been characterized morphologically, agronomically, and with few molecular markers (6 SSR primers). Initial results suggest that ½ of the collection consist of duplicates. In addition, some initial crosses among climbing beans and selections have been made by the ICTA group. These lines will be used intensively in this project.

III. Technical Research Progress

Objective 1: Development of germplasm with improved disease resistance and agronomic performance.

Collaborators:

NDSU: Juan M. Osorno and Phil McClean.

ICTA: Julio Cesar Villatoro, Angela Miranda, Jessica Moscoso, Karen Agreda, Edgardo Carrillo.

1.1: Validation plots and release of at least 1 climbing bean cultivar (ICTA): After 3 years of farmer's field testing (see previous annual reports), two varieties have been officially released during FY2017. ***ICTA Utatlan,*** a climbing bean adapted to the high altitude of Guatemala's western highlands (1,500 to 3,000 meters above sea level) and the milpa cropping system practiced in these mountainous regions, matures a month earlier than other climbing bean varieties and produces greater yields than the local landrace bean usually planted in the highlands. This early maturing and additional 200 kg/ha (ha=2.47 acres) sets ICTA Utatlan apart for resource-poor smallholder farmers, who often suffer during the seasonal hunger period between June and September, when the previous season's food stores are depleted and the new crop is not yet ready for harvesting. ***ICTA Labor Ovalle,*** a small, black Bolonillo seed type with a shiny appearance that is also adapted to growing in the elevated mountain regions of western Guatemala and produces an average yield 172 kg/ha greater than the local landrace bean, has also been received enthusiastically by highland farmers. As a Bolonillo seed type, ICTA Labor Ovalle is considered a preferred market class that is highly valued in the marketplace. Additionally, both farmers and buyers have praised its excellent taste, shorter cooking time, and wonderful broth color—all characteristics valued by buyers, making it an excellent cash crop for smallholder farmers who want to increase their household income. Bolonillo beans sell for about $1.50/lb., making it a profitable bean. Officially released in March 2017 at the ICTA (Instituto de Ciencia y Technologia Agricolas) Centro Regional de investigacion del Altiplano Occidental, just outside Quetzaltenango, Guatemala, at the Liberacion Oficial de Variedades de Semillas de Frijol event, both of these bean varieties were initially developed by Dr. Fernando Aldana, a bean breeder at ICTA Quetzaltenango (now retired).

The last breeding stages, seed purification and production, and release were made with support from the Feed the Future Innovation Lab for Collaborative Research on Grain Legumes project, *Genetic Improvement of Middle-American Climbing Beans for Guatemala*, in cooperation with ICTA and the Feed the Future Buena Milpa and MASFRIJOL projects. Event participants received 1.5 kg. of each bean seed at the event for planting. Buena Milpa distributed approximately 7,000 pounds of each seed during the 2017 planting season, and ICTA is producing more seed of these varieties for distribution to farmers in the 2018 season. The Feed the Future MASFRIJOL project also received 200 pounds of each variety for distribution.
A third line named ICTA-Texel is the last stages of seed purification before it can be released. Phenotypic variation for pod color and seed shape was found in the seedstock and therefore, efforts are currently underway to ensure homozygosity within this variety. This line offers a great combination of high seed yield but reduced climbing aggressiveness, which is a negative trait present in many high yielding climbing bean genotypes.

1.2: Breeding pipeline (ICTA/NDSU): The breeding pipeline continues to move genetic material through different stages. During FY2017, 23 new crosses were made. A total of 57 advanced lines obtained from individual plant selections and purifications made during the last 2 years (objective 1.3) were evaluated in replicated field trials at the ICTA stations in Chimaltenango and Quetzaltenango. This number includes individual plant selections made within heterogeneous lines (based on overall disease resistance/tolerance, pod load, color, and seed type). An average of 3 individual plants were selected within lines of interest. This material was planted again during FY2017 at ICTA-Quetzaltenango for field evaluation under trellis conditions (Monoculture instead of intercropping to facilitate visual selection). Phenotypic selection will be practiced again. Selected advanced lines will be given to ICTA to continue field testing in subsequent years beyond FY2017 if additional funding is available after this 4-year cycle.

1.3: Genetic purification of selected advanced lines (ICTA/NDSU): A final effort to purify the advanced lines will be made if genetic heterogeneity is visually detected. During the 2016 growing season, ?? plants with apparent superior performance (e.g. disease resistance, seed yield, pod distribution, seed quality, climbing aggressiveness, earliness, etc.) were tagged and individually harvested as a single plant selections. The seed from each individual plant selected was grown in the off-season nursery at San Jeronimo in FY2017 for: i) seed increase, and ii) further evaluations. A total of ?? individual plants were selected and planted during the 2017 growing season at ICTA-Quetzaltenango and are currently being selected based on agronomic traits at the time of this report.

1.4: Third crossing block (ICTA/NDSU): Another set of crosses was made during the 2017 growing season at the ICTA-Chimaltenango station in order to keep feeding the breeding pipeline (Objective 1.2). At least 40 new parental combinations were attempted in order to create new segregant populations that can be used for selection in later generations. All this material contributes to the breeding pipeline (objective 1.2) that will help to establish a long-term breeding program that will continue developing improved climbing beans adapted to the region in the future. It is important to note that besides the breeding efforts made by CIAT on climbing beans, this is the second breeding program focused on climbing beans in the western hemisphere.

Objective 2: Characterization of the genetic diversity of this unique set of germplasm.

Collaborators:
NDSU: Juan M. Osorno and Phil McClean.
ICTA: Julio Cesar Villatoro and Angela Miranda.

2.1 Evaluation of core collection with the 6k SNP chip (NDSU): After some discussion within the research group and some cost analysis, it was decided to genotype the ICTA climbing bean collection using a newer GBS approach that allows for far more markers than the 6k chip. By using a two-restriction enzyme procedure (*Mse*I and *Taq*α1), a total of 102,000 SNP markers were obtained. After SNP calling and filtering, 45,128 SNPs remained for the genetic diversity study. Besides 369 accessions from the ICTA climbing bean collection, the following plant material was also analyzed in order to be able to make comparisons among the different genetic groups:

- 260 Guatemalan accessions from the new collection obtained from the grower’s survey.
- Mesoamerican Diversity Panel (MDP):
    - 100 accessions of race Mesoamerica.
    - 100 accessions of race Durango-Jalisco.
- Andean Diversity Panel (ADP):
    - 135 accessions mostly of race Nueva Granada.
- 12 wild accessions from Guatemala (USDA-GRIN).

2.2 SNP Evaluation of the new Guatemalan collection (NDSU): A total of 452 samples of beans were donated by local farmers as part of the grower's survey made during FY2015 (Objective 3). This came in the form of donations from 1-2 seeds to several dozen seeds. These are seeds represent the beans that are currently being grown throughout the highlands of Guatemala, the target region of the project. This is a major new resource that needs full characterization both phenotypically and genotypically. In addition, an additional 48 samples were provided by an additional ICTA collection made during 2014. Of the 500 samples, 420 contained only a single seedtype (black, red, white). Sequence-based SNP data from this new collection will be compared with the SNP data from the original collection housed at ICTA. A major advantage of this newer collection is that passport data (GPS coordinates, location, altitude, etc.) is available while this was lost for the original collection as mentioned in previous documents. We will attempt to do a geographical correlation between both collections using the gentotypic data obtained from both groups.

Similarly to the ICTA old collection explained above, a subset of 260 accessions of this new collection were also screened with the 45,128 SNPs previously mentioned. The main goal was to characterize the genetic diversity contained in this new collection and compare it with the old one. Results showed that Guatemalan climbing beans are a unique genetic group that can be genetically differentiated from other races/subgroups within the Middle American gene pool and even among gene pools (Figures 1, 2 and 3). In addition, estimates of intra-race genetic diversity are similar to other races from the Middle American gene pool (Table 1). Data was also used to do Genome-Wide Association studies (GWAS) and showed significant genomic regions associated with traits such as seed shape, adaptation (altitude), and disease resistance, among others. All these results allowed obtaining the following conclusions:

- Guatemalan climbing beans did not group with any of the previously defined races of common bean.
- Race Guatemala represents a new source of genetic diversity.
- Genomic regions were associated with several traits of economic importance.
- Genomic regions were associated with local adaptation in the Guatemalan climbing beans.

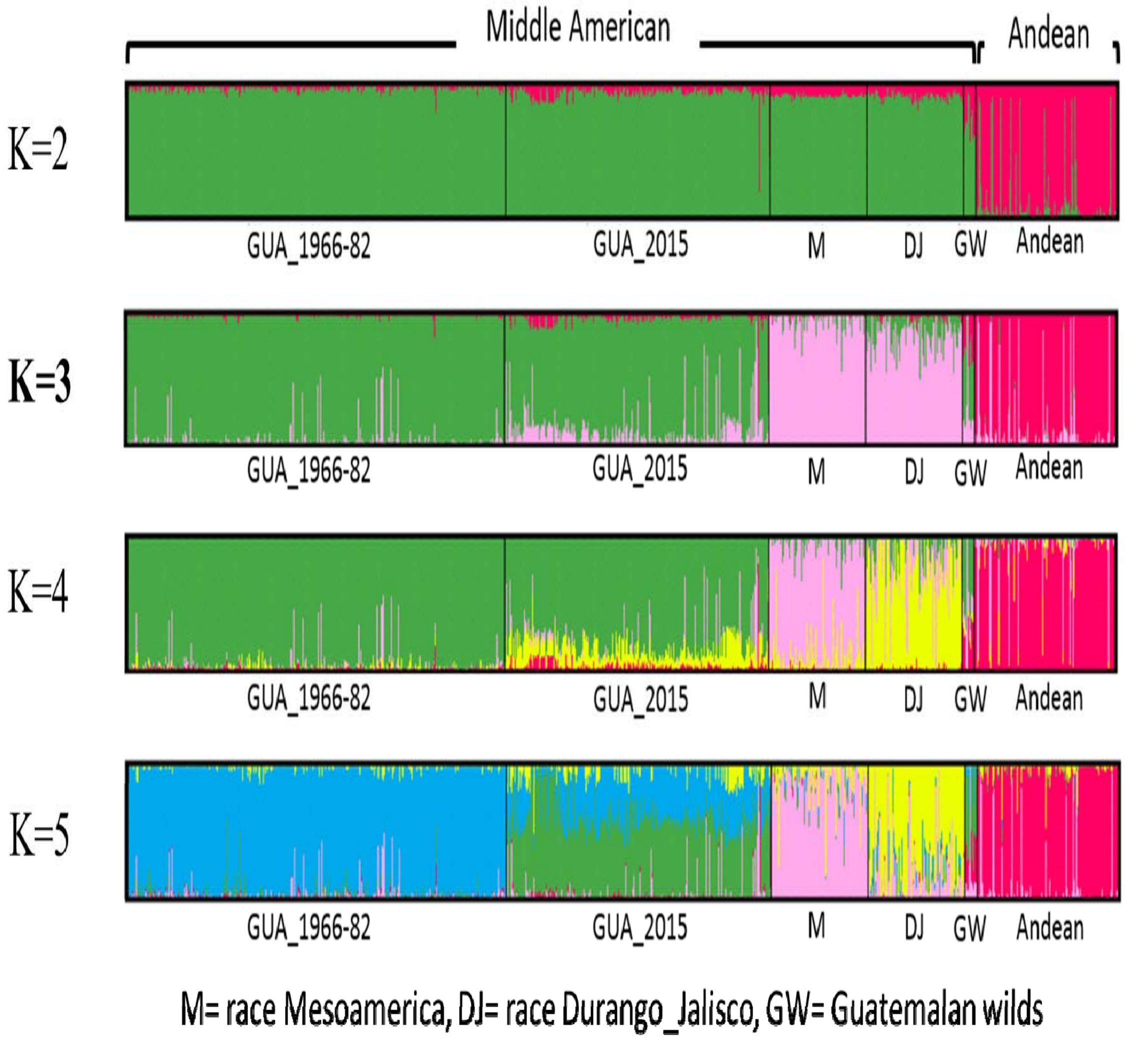

Figure 1. Population structure of different populations of beans. GUA_1966-82 represents the old collection and GUA_2015 represents the new collection. K=3 was the structure with the highest level of significance.

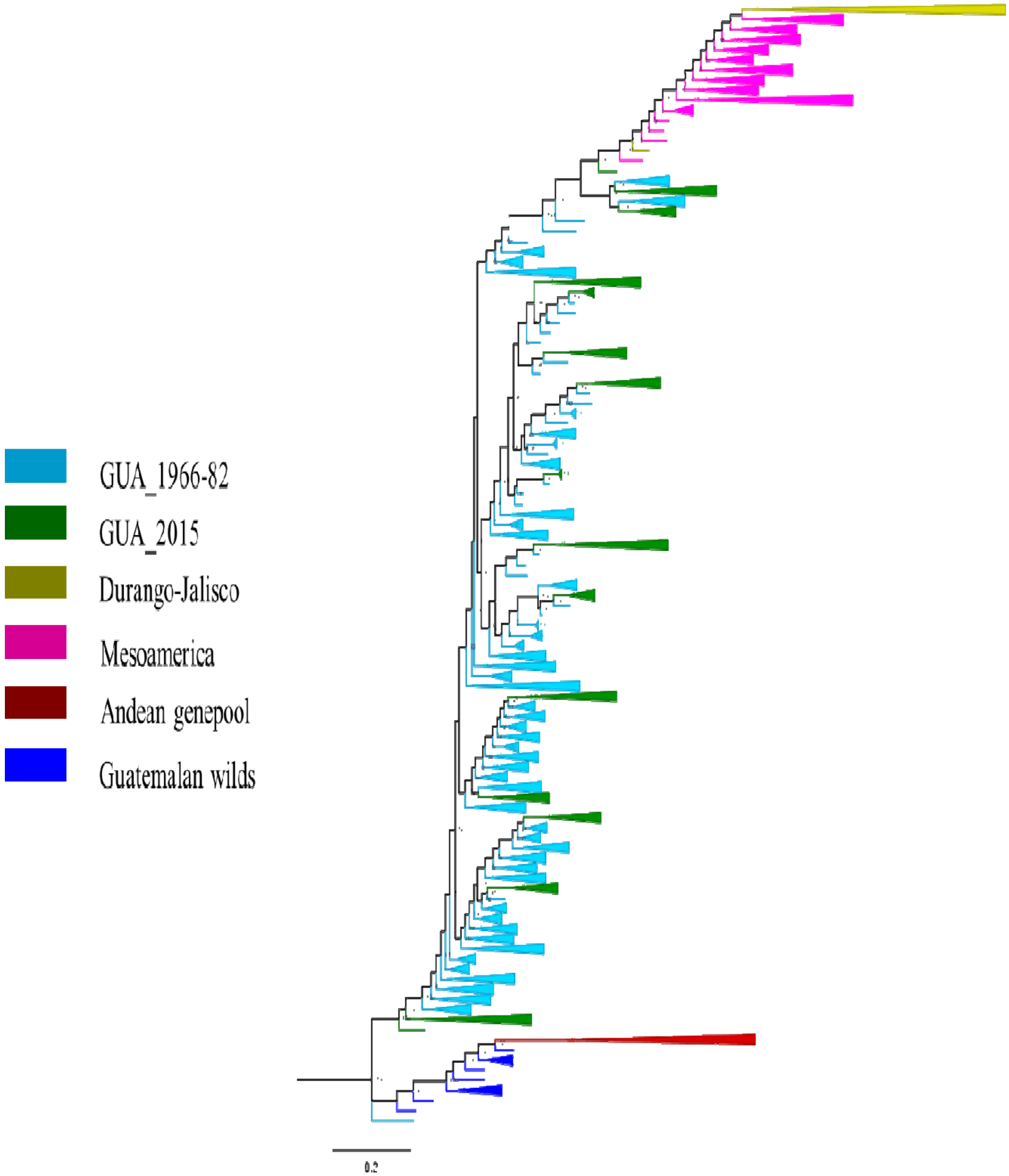

Figure 2. Condensed phylogenetic tree showing the groups of genetic diversity based on SNP similarity.

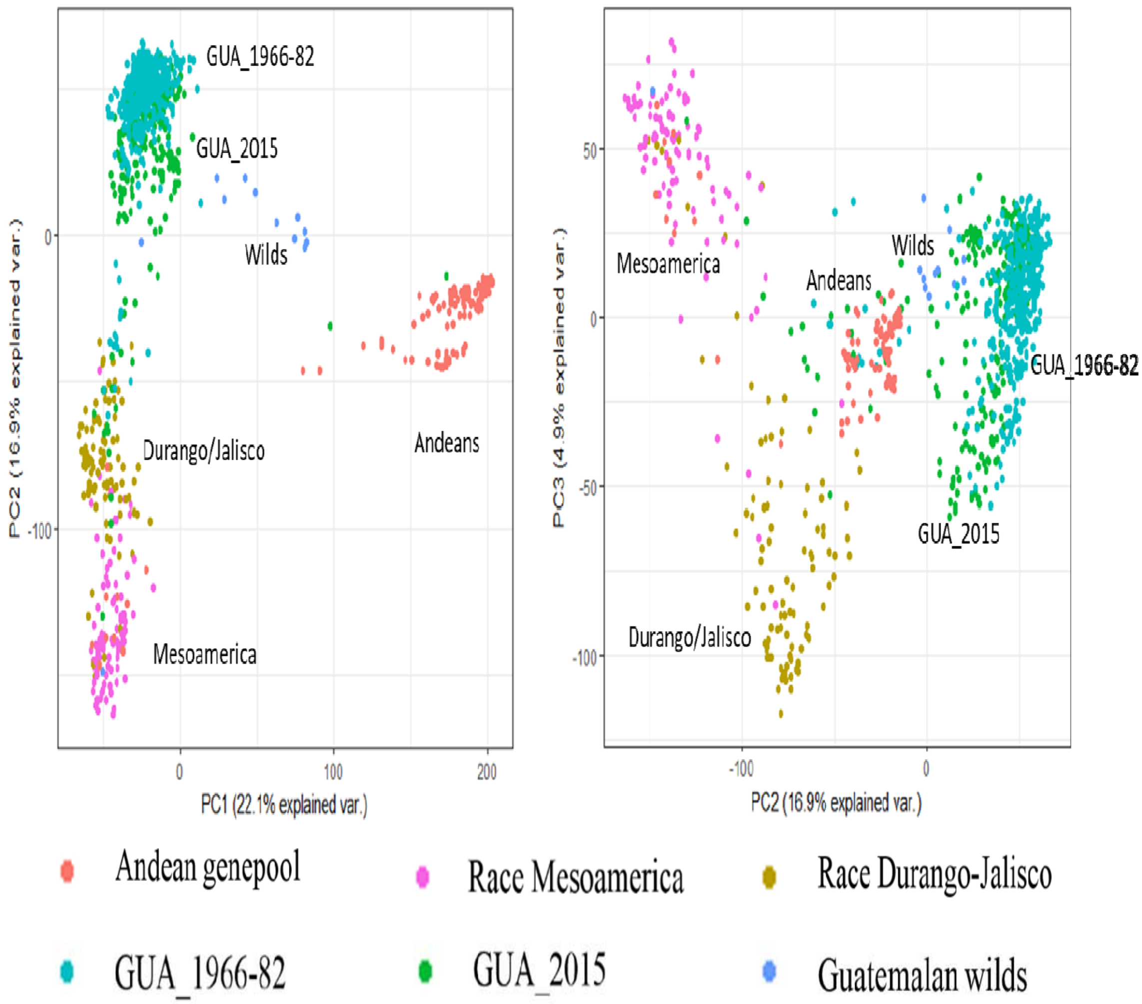

Figure 3. Principal component analyses showing groups of genetic diversity. GUA_1966-82 represents the old collection and GUA_2015 represents the new collection

Table 1. Genetic diversity statistic parameters for different bean sub-populations. GUA_1966-82 represents the old collection and GUA_2015 represents the new collection MA=Middle American; H_e=Expected heterozygosity; H_o=Observed heterozygosity; PIC=polymorphic information content; ΔH=Diversity loss.

Subpopulation	Genotypes (n)	% Polymorphic SNPs	H_e	H_o	PIC values	ΔH
MA genepool	819	100.00	0.38	0.34	0.30	-
GUA-1966-82	369	99.28	0.31	0.32	0.25	0.11
GUA-2015	260	99.83	0.36	0.35	0.28	-0.03
Mesoamerica	95	97.27	0.34	0.35	0.26	-
Durango-Jalisco	95	96.87	0.35	0.36	0.27	-
Guatemalan wild	12	94.83	0.35	0.31	0.28	-
Andean genepool	138	99.93	0.24	0.17	0.20	-
Entire population	971	100.00	0.41	0.31	0.32	-

2.3 Field evaluation of the newer ICTA collection of climbing beans (ICTA/NDSU): A final evaluation of selected accessions from the new germplasm collection obtained from the grower survey (see objective 3.2) was done at the ICTA station in Chimaltenango during the growing season of 2017 to allow a re-evaluation of the material and also the production of a newer batch of seed of genotypes with traits of interest based on the initial evaluation during the 2016 growing season. Approximately 200 accessions were selected in 2016 and planted in 2017. Within this group, 24 of these accessions are *P. coccinueus*, 152 *P. dumosus*, and 24 *P.vulgaris* and they are currently being harvested at the time of this report.

Each accession was planted in short rows (~2 m) in a trellis system mostly for phenotypic observation. The following traits were recorded: disease reaction under natural conditions (Ascochyta, Rust, Anthracnose), earliness, biomass/climbing aggressiveness, seed yield potential, and pod distribution (upper vs. homogeneous distribution). Selected germplasm will be used in future crosses.

Objective 3: A better understanding of the current socio-economic status and needs of bean

production within the context of intercropping systems in the region.

Collaborators:
NDSU: Juan M. Osorno.
ICTA: Julio Cesar Villatoro, Jessica Moscoso, Angela Miranda.
MSU: Mywish Maredia and David DeYoung.

Approaches and Methods:

3.1 Final statistical analyses of survey data and publication of results (ICTA/MSU/NDSU): Final statistical analyses and publication of results were the remaining activities of this objective. The survey activity was very successful thanks to a great collaboration established with the project lead by Mywish Maredia (SO4.1). They have far more experience with surveys than any person in our team, so we appreciate their willingness to help. In the same way Gustavo Mejia, a social economist at ICTA-Quetzaltenango was of key importance in coordinating this activity. Results of this survey are available in a separate staff paper/report titled "An Overview of Bean Production Practices, Varietal Preferences, and Consumption Patterns in the *Milpa* System of the Guatemalan Highlands: Results of a Farm Household Survey". Staff Paper No. 2017-08, Department of Agricultural, Food and Resource Economics
Michigan State University. This report is available under request.

The study of climbing bean farmers in the five departments (Quiche, Huehuetenango, San Marcos, Chimaltenango and Quetzaltenango) of the *Altiplano* region of Guatemala confirms the importance of beans as a crop for own consumption in the study area. On average, households planted 0.4 hectares to beans in the study region. Beans, planted as part of the traditional intercropped system called *milpa,* are most commonly planted simultaneously (or directly) with corn in the plots of farmers interviewed while relay (*milpa relay)* was a second common planting method in the study area. In terms of area planted, most farmers ranked beans as the first or second most important crop. A majority of farmers do not sell harvested grain. Indeed for many farmers own bean production is not sufficient to cover annual household bean consumption, and they rely on purchased beans to fill this deficit. Bean consumption among households in this region is highest after harvest (often between October and January in the region) and lowest in July, August and September. The study confirms that men and women farmers have slightly different preferences for bean seed varietal traits and women are willing to pay more for bean seed of varieties with their preferred traits than men. On average, farmers indicated they are willing to pay only a 10% premium for bean seed of preferred variety over the price of grain. Thus any efforts to increase the use of new improved varieties of beans to promote productivity growth in this region will need to be based on subsidized seed dissemination efforts to make the seeds affordable by smallholder farmers in this region of Guatemala. A staff paper (2017-08) from Michigan State University reports in more detail the findings of this activity.

3.2 Conditioning and storage of seed samples collected during the survey (ICTA): During the deployment of the survey during FY2015, growers were asked to provide a small seed sample of the variety or varieties they commonly grow in their farms. After seed increases made during the 2016 and 2017 growing seasons, seed will be conditioned and stored at the cold seed room available at the ICTA-Chimaltenango station. A total of 490 new accessions will be stored and made available to the bean scientific community.

Objective 4: Capacity building: training the next generation of plant breeders for Guatemala and establishing a long-term breeding plan to increase the productivity of climbing bean in the region.

4.1. Graduate Students (NDSU): Out of the three students under this project, one has completed her M.S. degree and two more will be completed in late November 2017.

4.2. Long-term breeding plan (ICTA/NDSU): A document describing a long term plan to continue breeding activities for climbing beans was developed by the ICTA bean team in collaboration with NDSU. This document will help to be a future roadmap regardless of the availability of funds in the future. If future funding opportunities arise, this document will facilitate the writing of a new project that will keep the momentum gained during this 4 year cycle.

4.3. Plant Breeding workshop (ICTA/NDSU): Because of schedule conflicts with other meetings and activities, this workshop was canceled. We hope to make another attempt in the future if funds become available.

IV. Major Achievements

Objective 1:

- Release of two new varieties: ICTA-Labor Ovalle and ICTA-Utatlan. The most impactful accomplishment of this project for the future productivity and food security in the western highlands.
- Creation and maintenance of a breeding pipeline for climbing beans: Only two breeding programs focused on climbing beans exist in the western hemisphere (CIAT and ICTA). However, the CIAT program focuses on Andean climbing beans while the one at ICTA is focused on Middle American climbing beans.
- Newer elite lines that may be released in the near future: ICTA-Texel is another climbing bean with high yield and reduced climbing aggressiveness that could be released in the near future.

Objective 2:

- Genetic characterization of two germplasm collections of climbing beans using 42k SN P markers: Results confirmed the presence of a new distinct race within the Middle American gene pool known as race Guatemala. Results also allowed the identification of important genomic regions associated with traits of agronomic/economic importance for future breeding purposes.

Objective 3:

- Results from the grower survey will allow a better understanding of the current situation of bean production and consumption in the western highlands of Guatemala. This information will be critical for planning new strategies for food security in the region.

Objective 4:

- Three individuals from ICTA obtained their M.S. degrees and are returning to their home countries to apply all the skills and training received. This is a great contribution to capacity building within ICTA Guatemala.
- The long-term breeding plan is a master document that will help in the planning of future projects for breeding climbing beans in the region.

V. Research Capacity Strengthening

A capacity strengthening grant was obtained to help ICTA to implement a drip irrigation system at the Chimaltenango station. This system was used for the first time during the 2017 growing season and this field has been permanently assigned to bean research. However, some crop rotation will be needed in order to avoid the increase in fungal and insect populations causing root diseases/problems that may affect bean agronomic performance or hinders selection at this site. In addition, the seed cold storage conditions were improved thanks to a new air conditioning unit and a new dehumidifier. This equipment will ensure that hi quality research will continue at ICTA for many years and germplasm obtained through this funding cycle will be conserved in the best possible conditions.

VI. Human Resource and Institution Capacity Strengthening

1. Short-Term Training

i. Nothing to report.

2. Degree Training in the US or elsewhere

i. Name of trainee: Luz de Maria Montejo
ii. Country of Citizenship: Guatemala
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: ICTA-Guatemala
v. Institution providing training: NDSU
vi. Supervising LIL PI: Juan M. Osorno and Phil McClean
vii. Degree Program: M.S. Plant Sciences
viii. Field or Discipline: Plant breeding/pathology

Research Project Title: Rust resistance in Guatemalan climbing bean germplasm collection.

Projected/Actual Completion Date: September 2017

ix. Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
x. Training status (Active, Completed, Pending, Discontinued, or Delayed): Completed

xi. Name of trainee: Maria Gabriela Tobar-Piñon
xii. Country of Citizenship: Guatemala
xiii. Gender: Female
xiv. Host Country Institution Benefitting from Training: ICTA-Guatemala
xv. Institution providing training: NDSU

xvi. Supervising LIL PI: Phil McClean and Juan M. Osorno
xvii. Degree Program: M.S. Plant Sciences
xviii. Field or Discipline: Plant breeding/genomics
Research Project Title: Molecular characterization of germplasm collection of Guatemalan climbing beans
Projected/Actual Completion Date: November 2017
xix. Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
xx. Training status (Active, Completed, Pending, Discontinued, or Delayed): Active

xxi. Name of trainee: Carlos Maldonado-Mota
xxii. Country of Citizenship: Guatemala
xxiii. Gender: Male
xxiv. Host Country Institution Benefitting from Training: ICTA-Guatemala
xxv. Institution providing training: NDSU
xxvi. Supervising LIL PI: Juan M. Osorno and Phil McClean
xxvii. Degree Program: M.S. Plant Sciences
xxviii. Field or Discipline: Plant breeding/pathology
Research Project Title: Anthracnose resistance in Guatemalan climbing bean germplasm collection.
Projected/Actual Completion Date: November 2017
xxix. Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
xxx. Training status (Active, Completed, Pending, Discontinued, or Delayed): Active

VII. Achievement of Gender Equity Goals

The ICTA bean breeding program includes at least three women in their team (Angela Miranda, Jessica Moscoso, and Karen Agreda), some of them in leading positions (Angela is the new program leader now that Julio Villatoro has been named ICTA subdirector). They are in charge of all the activities at San Jeronimo and Quetzaltenango. In addition, 2 women who are ICTA employees (Gabriela Tobar and Luz Montejo) just completed their graduate degrees (M.S. in Plant Sciences) at NDSU.

VIII. Implementation of Data Management Plan

A revised data management plan was submitted to the Legume Innovation Laboratory Management Office. Scientists interested in using a data set generated with support from the Legume Innovation Lab should contact the PI or Co-PI responsible for generating the data set to confirm how and for what purpose the data was collected. The PI or Co-PI responsible for maintaining the data set will deposit the information in the USAID Development Data Library (DDL).

IX. Scholarly Accomplishments

Agreda, K.A., Osorno, J.M., McClean, P.E., Villatoro, J.C., Miranda, A.N., Moscoso, J.R. 2017. Phenotypic Evaluation of Native Accessions of Climbing Beans Collected in the Guatemala Highlands. Oral session presented at: Programa Cooperativo Centroamericano Para el Mejoramiento de Cultivos y Animales PCCMCA. San Salvador, El Salvador. May. 15th to 19th. [In Spanish]

Agreda, K.A., Osorno, J.M., McClean, P.E., Villatoro, J.C., Miranda, A.N., Moscoso, J.R. 2017. Phenotypic Evaluation of Native Accessions of Climbing Beans Collected in the Guatemala Highlands. Poster session presented at: Grain Legume Research Conference. Ouagadougou, Burkina Faso. Ag. 13th to 18th.

DeYoung, D., Reyes B., Mejia G., Tucux M., Vasquez M., Santos J.J., Villatoro J.C., Montejo L.M., Moscoso J.R., Osorno J.M., and Maredia M. 2017. Gender Differences in Varietal Preferences and Willingness to Pay for Quality Bean Seeds: Evidence from the Guatemalan Highlands. Poster Session presented at: Feed the Future Innovation Lab for Collaborative Reserch on Grain Legumes. Ougadougou, Burkina Faso. August 13-18th.

Maldonado-Mota C.R., Pastor-Corrales M.A., Hurtado-Gonzales O.P., Moghaddam S.M., Schroder S., McClean P.E., Pasche J., Lamppa R., Tobar-Piñon M.G., Villatoro-Merida J.C., Miranda A.N, Moscoso J.R., Agreda K., and Osorno J.M. 2017. Identification of new sources of resistance to anthracnose in climbing bean germplasm from Guatemala. Poster Session presented at: Feed the Future Innovation Lab for Collaborative Reserch on Grain Legumes. Ougadougou, Burkina Faso. August 13-18th.

Maldonado-Mota C.R., Pastor-Corrales M.A., Hurtado-Gonzales O.P., Moghaddam S.M., Schroder S., McClean P.E., Pasche J., Lamppa R., Tobar-Piñon M.G., Villatoro-Merida J.C., Miranda A.N, Moscoso J.R., Agreda K., and Osorno J.M. 2017. Virulence diversity of Colletotrichum lindemuthianum in Guatemala and GWAS to identify genomic regions associated with anthracnose resistance in common bean. Oral session presented at: The Biennial Bean Improvement Cooperative Conference, East Lansing, Michigan, United States. Oct. 29th to Nov.1st

Maldonado-Mota C.R., Pastor-Corrales M.A., Hurtado-Gonzales O.P., Moghaddam S.M., Schroder S., McClean P.E., Pasche J., Lamppa R., Tobar-Piñon M.G., Villatoro-Merida J.C., Miranda A.N, Moscoso J.R., Agreda K., and Osorno J.M. 2017. Identification of new sources of resistance to anthracnose in climbing bean germplasm from Guatemala. 2017. Oral session presented at: Plant Sciences Symposium, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, March 31st to April 1.

McClean, P.E. 2017. Targeted Improvement of the Mayan Milpa Cropping System in Guatemala. Invited speaker at CROPS conference at HudsonAlpha Institute of Biotechnology, Huntsville, AL.

Montejo L.M., Steadman J., Villatoro J.C., Moscoso J., Agreda K., Osorno J.M. 2016. Rust Resistance in the Guatemalan Climbing Bean Germplasm Collection, Preliminary results. Poster session presented at: ASA-CSSA & SSSA Annual meeting. Phoenix, Arizona, U.S. Nov. 6 th to 9 th

Montejo L.M., Steadman J., Villatoro J.C., Moscoso J., Agreda K., McClean P., Osorno J.M. 2017. Rust Resistance in the Guatemalan Climbing Bean Germplasm Collection. Oral session presented at: Plant Science Graduate Students Symposium. University of Saskatchewan, Saskatoon, Canada. March 31st to April 1st.

Montejo L.M., Steadman J., Villatoro J.C., Moscoso J., Agreda K., McClean P., Osorno J.M. 2017. Rust Resistance in the Guatemalan Climbing Bean Germplasm Collection, Final Results. Oral session presented at: Grain Legume Research Conference. Ouagadougou, Burkina Faso. Ag. 13th to 18th.

Moscoso,J.R., Villatoro, J.C., Miranda, A.N., Carrillo, E.E., Agreda, K.A., Aldana, L.F, Osorno, J.M., McClean, P.E. Release of Two Varieties of Climbing Bean: ICTA Labor Ovalle Bolonillo e ICTA Utatlán in Guatemala. Oral session presented at: LXII Reunión Anual del Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales (PCCMCA), San Salvador, El Salvador. May. 16th to 19th. [In Spanish]

Moscoso,J.R., Villatoro, J.C., Miranda, A.N., Carrillo, E.E., Agreda, K.A., Aldana, L.F, Osorno, J.M., McClean, P.E. Agroeconomic Evaluation of Three Varieties of Climbing Bean (Phaseolus vulgaris L.), Grown in Three Spacial Arrangements. Poster session presented at: Grain Legume Research Conference. Ouagadougou, Burkina Faso. Ag. 13th to 18th

Osorno, J.M., McClean, P.E., Villatoro, J.C., Miranda, A.M., Moscoso, J.R., Agreda, K.A., Aldana, L.F. 2017. Two New Climbing Bean Varieties Adapted to the Milpa System in the Highlands of Guatemala. Oral session presented at: Grain Legume Research Conference. Ouagadougou, Burkina Faso. Ag. 13th to 18th.

Tobar-Piñón M.G., Mogghadam S.M., Lee R.K., Villatoro J.C., Osorno J.M., McClean P.E. 2016. Genetic Diversity of the Guatemalan Climbing Bean Collection. Second International Legume Society Conference. Troia, Portugal. Oct. 11th to Oct. 14th.

Tobar-Piñón M.G., Mogghadam S.M., Lee R.K., Villatoro J.C., Osorno J.M., McClean P.E. 2017. Genetic Diversity of the Guatemalan Climbing Bean Collection. 33rd Annual Plant Science Graduate Student Symposium. Saskatoon SK, Canada. Mar. 31st to Apr. 01st.

Tobar- Piñón M.G., Mogghadam S.M., Lee R.K., Villatoro J.C., Osorno J.M., McClean P.E. 2017. Genetic Diversity of the Guatemalan Climbing Bean Collection. Central America Cooperative Program for Crop and Animal Breeding, PCCMCA. San Salvador, El Salvador. Apr. 25th to Apr. 28th. [In Spanish]

Tobar- Piñón M.G., Mogghadam S.M., Lee R.K., Villatoro J.C., Osorno J.M., McClean P.E. 2017. Genetic Diversity of the Guatemalan Climbing Bean Collection. Legume Innovation Lab Grain Legume Research Conference. Ouagadougou, Burkina Faso. Aug. 13th to Aug. 18th.

Tobar- Piñón M.G., Mogghadam S.M., Lee R.K., Villatoro J.C., Osorno J.M., McClean P.E. 2017. Genetic Diversity of the Guatemalan Climbing Bean Collections. Bean Improvement Cooperative Conference. East Lansing MI, USA. Oct. 29th to Oct. 31st.

Tobar- Piñón M.G., Mogghadam S.M., Lee R.K., Villatoro J.C., Osorno J.M., McClean P.E. 2017. Genetic Diversity of the Guatemalan Climbing Bean Collection. Plant and Animal

Genome Conference, PAG. San Diego CA, USA. Jan. 13th to Jan. 17th.

Montejo-Domínguez, L. de M. 2017. Rust resistance in the Guatemalan climbing bean collection. M.S. Thesis. North Dakota State Univ. 76 p.

Maldonado-Mota, C. 2017. Identification of new sources of resistance to Anthracnose in climbing bean germplasm from Guatemala. M.S. Thesis. North Dakota State Univ. 70 p.

Tobar-Piñon, M.G. 2017. Genetic diversity of the Guatemalan climbing bean collections. M.S. Thesis. North Dakota State Univ. 109 p.

X. Achievement of Impact Pathway Action Plan

Our project has been able to accomplish all the items and activities proposed in our impact pathways. The only exception was the plant breeding workshop which could not be done because of several schedule conflicts with other meetings and activities.

Feed the Future Innovation Lab for Collaborative Researchon Grain Legumes

Report on the Achievement of "Milestones of Progress"
(For the Period: October 1, 2016-- March 31, 2017)

This form should be completed by the U.S. Lead PI and submitted to the MO by April 1, 2017

Project Title: 0

	Abbreviated name of institutions																	
	NDSU			ICTA			Institution 3			Institution 4			Institution 5			Institution 6		
	Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved	
Milestones by Objectives	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*
	(Tick mark the Yes or No column for identified milestones by institution)																	
Objective 1	Development of germplasm with improved disease resistance and agronomic performance.																	
1.1. Validation plots	0			X	X		0			0			0			0		
1.2 Breeding pipeline	0			X	X		0			0			0			0		
1.3. Genetic purification of selected adv.lines	0			X	X		0			0			0			0		
1.4 Third crossing block	0			X	X		0			0			0			0		
0	0			0			0			0			0			0		
Objective 2:	Characterization of the genetic diversity of this unique set of germplasm																	
2.1 SNP evaluation of core collection	X	X		0			0			0			0			0		
2.2 SNP evaluation of the new collection	0			0			0			0			0			0		
2.3 Field evaluation of the new collection	0			X	X		0			0			0			0		
0	0			0			0			0			0			0		
0	0			0			0			0			0			0		
Objective 3:	A better understanding of the current socio-economic status and needs of bean production within the context of intercropping systems in the regic																	
3.1 Final analyses of survey data and publication	X	X		0			0			0			0			0		
3.2 Conditioning and storage of seed samples	0			X	X		0			0			0			0		
0	0			0			0			0			0			0		
0	0			0			0			0			0			0		
0	0			0			0			0			0			0		
Objective 4:	Capacity building: training the next generation of plant breeders for Guatemala and establishing a long-term breeding plan.																	
4.1 Two graduate students at NDSU	0			0			0			0			0			0		
4.2 Long-term breeding plan	X	X		X	X		0			0			0			0		
0	0			0			0			0			0			0		
0	0			0			0			0			0			0		
0	0			0			0			0			0			0		
Name of the PI reporting on milestones by institution	PI name JUAN OSORNO			PI name JULIO VILLATORO			PI name			PI name			PI name			PI name		

Name of the U.S. Lead PI submitting this Report to the MO

JUAN M. OSORNO

Signature **Date**

* *Please provide an explanation for not achieving the milestones on a separate sheet.*

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes
REVISED PERFORMANCE INDICATORS / TARGETS SPREADSHEET for FY 14, FY 15, FY16, and FY 17

Project N SO1.A1

Institution 1 Name (one sheet per instittition):

Indic. numbe	Output Indicators	FY 14 Target	FY 14 Revised	FY 14 Actual	FY 15 Target	FY 15 Revised	FY 15 Actual	FY 16 Revised	FY 16 Actual	FY 17 Target	FY 17 Revised	FY 17 Actual	FY18 Target	FY 18 Revised	FY 18 Actual
		(October 1, 2013 - September 30, 2014)			(October 1, 2014 - September 30, 2015)			tober 1, 2015 - September 30, 20		(October 1, 2016 - September 30, 2017)			(Oct 1, 2017 - Nov 30, 2017)		
1	4.5.2(6) Degree Training: Number of individuals who have received degree training	0	0	0	2	3	2	2	3	3	3	0	0	0	0
	Total number by sex	0	0	0	2	3	2	2	3	3	3	0	0	0	0
	Number of women	**0**	**0**	0	**2**	**2**	1	**1**	2	**2**	**2**				
	Number of men	**0**	**0**	0	**0**	**1**	1	**1**	1	**1**	**1**				
	Total number by New/continuing	0	0	0	2	3	2	2	3	3	3	0	0	0	0
	New	**0**	**0**	0	**2**	**3**	2	**2**	0	**0**	**0**				
	Continuing	**0**	**0**	0	**0**	**0**	0	**0**	3	**3**	**3**				
2	4.5.2(7) Short-term Training: Number of individuals who have received short-term training	20	14	75	65	140	135	78	897	825	825	927	0	0	0
	Total number by sex	20	14	75	65	140	135	78	897	825	825	927	0	0	0
	Number of women	5	4	55	20	95	110	27	348	310	310	455			
	Number of men	15	10	20	45	45	25	51	549	515	515	472			
	Numbers by Type of individual	20	14	75	65	140	135	78	897	825	825	927	0	0	0
	Producers	15	10	9	40	130	125	50	868	800	800	540	0	0	0
	Number of women								335	300	300	265			
	Number of men								533	500	500	275			
	People in government	5	4	7	20	10	10	28	29	25	25	373	0	0	0
	Number of women								13	10	10	183			
	Number of men								16	15	15	190			
	People in private sector firms	0	0	50	5	0	0	0	0	0	0	14	0	0	0
	Number of women								0	0	0	7			
	Number of men								0	0	0	7			
	People in civil society	0	0	9	0	0	0	0	0	0	0	0	0	0	0
	Number of women								0	0	0				
	Number of men								0	0	0				
3	4.5.2(39) Number of new technologies or management practices in one of the following phases of development: (Phase I/II/III)	0	0	0	20	20	20		20	23					
	Phase 1: Number of new technologies or management practices under research as a result of USG assistance	0	0	0	10	10	10	10	10	10	10	10	2		
	Phase 2: Number of new technologies or management practices under field testing as a result of USG assistance	0	0	0	10	10	10	10	10	10	10	10	2		
	Phase 3: Number of new technologies or management practices made available for transfer as a result of USG assistance	0	0	0	0	0	0	0	0	3	3	2	1		

Notes:
These indicators are developed under the Feed the Future Monitoring System. Pleas provide disaggregated numbers. Totals are automated.

This table corresponds to the Feed the Future Performance Indicators data collection sheet under the FTFMS system. Leave blank any aspect that does not apply to you.
Additional guidance here: https://agrilinks.org/post/fy17-feed-future-monitoring-syste guidance

V. Improving Photosynthesis in Grain Legumes with New Plant Phenotyping Technologies (SO1.A2)

Lead U.S. Principal Investigator and University:
David M. Kramer Biochemistry and Molecular Biology and Plant Research Lab, Michigan State University

Collaborating Host Country and U.S. PIs and Institutions:
Kelvin Kamfwa, University of Zambia
Kennedy Muimui, ZARI, Zambia
Wayne Loescher, MSU
James Kelly, MSU
Tim Close, U.C. Riverside
Phil Roberts, U.C. Riverside
Maren Friesen, MSU, Plant Biology

I. Abstract of Research and Capacity Strengthening Achievements

(A succinct narrative on the technical progress of the project, including key research and capacity strengthening achievements and outcomes, during the FY 2017 performance and report period. 1200 character limit.)

In the previous year we met all of our objectives for FY 2017. The first critical step was the successful manufacturing of the next generation MultispeQ instrument, which has improved capabilities over the initial Beta MultispeQ. This allowed us to achieve our goals of enhancing the capabilities of our Feed the Future (FtF) research partners to 'bring the lab to the field' using advanced phenotyping technologies. We distributed new MultispeQ's v1.0 instruments and training to students, research technicians and faculty at the University of Zambia and Makerere University. Additionally, we renovated the irrigation system at the University of Zambia research farm. These capacity building activities enabled us to identify photosynthetic efficiency QTL's under drought conditions in the field at the University of Zambia.

Another key research goal was to bring the field to the lab. Using two different advanced phenotyping technologies, DEPI chambers and the PhotosynQ platform, we were able identify key QTL's for heat and cold tolerance. We identified comparable heat tolerant QTL's using both advanced phenotyping platforms and identified cold tolerance QTL's in two different RIL populations using PhotosynQ, and evaluating the lipid membrane and ATP synthase activity.

II. Project Problem Statement and Justification

To avert food shortages and feed its growing population, there is critical need for increasing the productivity of grain legumes in Zambia, which ranks 164 out of 184 countries in the Human Poverty Index. Grain legumes are important crops in Zambia constituting both critical sources of protein and income. Bean production is constrained by its low inherent photosynthetic efficiency which is highly sensitive to abiotic and biotic stresses, including diseases, pests, low soil fertility hear and drought.

To achieve major gains in yield, we need to improve both the robustness and the efficiency of photosynthesis. This is a complex problem requiring the combined application of advanced genomics and high throughput phenotyping approaches. We will take a critical step in this direction by establishing a base of phenotyping technologies and advanced genetics and genomics approaches to identify quantitative trait loci (QTLs) that condition more efficient and robust photosynthesis and productivity in cowpea and common beans. We will also test the ability of a newly developed research platform, PhotosynQ, to enable researchers and farmers to conduct plant phenotyping experiments, analyze data and share results, and thus allow improvements in breeding and management on local to global scales.

In previous years of the project we identified environmental conditions that aid in the identification of QTL's in common bean and cowpea. Furthermore, we successfully deployed PhotosynQ under field conditions in Zambia. However, a lack of infrastructure was constraining the development of a robust phenotyping center at the University of Zambia.

III. Technical Research Progress

Objective 1: Probing photosynthetic responses in RIL and GWAS lines.

During the past year we have successfully mapped QTL's in common bean and cowpea using two advanced phenotyping platforms; DEPI chambers and the PhotosynQ platform (Fig. 1). Using both platforms were we able to achieve comparable results for a RIL cowpea population (developed by the University of California Riverside) under both heat stress and normal growth conditions. Furthermore, we have identified a QTL for relative chlorophyll content and photoprotection (qEt) that coincided with biomass production under heat stress but not control conditions.

Additionally, we were able to map QTL's in 2 different RIL populations (provided by UC Riverside) for cold tolerance. These traits can be used to enable earlier planting in order to avoid heat stress. Additionally, we mapped the lipid membrane and ATP synthase to identify QTL's for photosynthetic efficiency, which allowed us to explore the mechanisms behind cold tolerance.

In the field we were able to identify key QTL's for higher photosynthetic efficiency under moisture stress conditions such as drought. This allows us to identify germplasm that will serve as parents in making crosses to develop varieties with preferred seed types that are tolerant to drought. Furthermore, we were able to identify the same QTL's under drought stress in multiple field trials, validating the PhotosynQ approach to identifying key QTL's.

Objective 2: Develop a data management plan to improve the communication of ideas, results, and analysis to a large network of connected scientists.

The PhotosynQ platform is set up to allow for rapid communication of ideas, results, and analyses. All data collected on the PhotosynQ platform is open, making it easy for scientists from around the world to connect and share results and analyses. All data collected with the support of the Legume Innovation Lab can be easily searched on the PhotosynQ platform (www.photosynq.org) using the hashtags #LIL and #LegumeInnovationLab.

Objective 3: Increase the capacity, effectiveness and sustainability of agriculture research institutions which serve the bean and cowpea sectors in the target FTF countries by establishing an African-USA community of networked scientists, extension agents, students and growers to address field-level research and production questions.

In FY 2017 we made major strides towards achieving this objective. One of the capacity development goals in this project is to turn the University of Zambia and Makerere University into cutting edge phenotyping centers. To that end, we have distributed 6 next generation MultispeQ v1.0 instruments to the University of Zambia and 5 MultispeQ v1.0 instruments to Makerere University. Dr. Kamfwa trained 4 research technicians from the Zambia Agricultural Research Institute and 1 Masters Student at UNZA on the PhotosynQ platform and MultispeQ instrument. Additionally, students and research technicians have collected over 19,000 phenotyping measurements on the common bean Andean Diversity Panel. PhD student Isaac Dramadri has trained students at Makerere University who have collected over 14,000 measurements on cowpea, groundnuts, and maize

In addition to training and instrumentation, we have made changes to the PhotosynQ website that improve the connectivity of phenotyping data to advanced analytics. This includes developing R and Python packages allowing users to directly import data from www.photosynq.org into these platforms for analysis. We have also increased the number of tutorials, help modules and analytical tools available on PhotosynQ to allow anyone, with minimal training, to pick up a MultispeQ instrument, create a robust PhotosynQ project, collect high quality data, and properly analyze the data. These tools will greatly enhance the ability of users at UNZA and Makerere University to harness the full potential of the PhotosynQ platform.

IV. Major Achievements

(*Present a* ***list of significant research achievements and/or technical advances resulting from project activities during the FY 2017 performance period****. The description of each* *achievement need not be more than three sentences long. Quantitative information on or a technical description of the research achievement would be appreciated because it adds credibility to the importance of the achievement.*)

1. Dissemination of the next generation MultispeQ v1.0 instrument. 6 new MultispeQ's were provided to the University of Zambia and 5 MultispeQ's to Makerere University in Uganda. In total, 500 next generation MultispeQ's were manufactured.
2. Identified QTL's related to cold tolerant photosynthetic efficiency using the PhotosynQ platform and evaluation of the lipid membrane and ATP synthase.
3. Identified comparable heat tolerance QTLs' using DEPI and PhotosynQ data in climate controlled growth chambers.
4. Identified drought tolerant QTL's under field conditions in Zambia.
5. Trained several graduate students at both UNZA and MSU, as well as research technicians from ZARI and students at Makerere University.
6. Development of new PhotosynQ-guided experimental protocols.

V. Research Capacity Strengthening

(*Describe how collaborative research activities supported by the project during FY 2017 have contributed to the strengthening of institutional capacity to carry out multidisciplinary research on grain legumes and to solve the problems facing the legume sectors in host countries and regions. Appropriate capacity strengthening items to present in this section include research equipment procured (>$5,000), laboratory and analytical facilities developed, participation in professional meetings or other networking activities, etc. Please also identify in this section the activities completed and equipment procured during the past fiscal year with supplemental Institutional Capacity Strengthening funds received by host country institutions in the respective project.)*

We have made progress in several areas of research capacity building.

First, Several LIL participants are currently using the PhotosynQ platform as a part of their LIL-supported work, including Kelvin Kamfwa (University of Zambia), Isaac Dramadri (Makerere University), Isaac Osei-Bonsu (in the Kramer lab at MSU) as well as several students working with collaborators Tim Close (U.C. Riverside), Phillip Roberts (U.C. Riverside) and Phil McLean (NDSU).

Second, we are actively working towards setting up cutting edge phenotyping centers at the University of Zambia and Makerere University in Uganda. At UNZA, faculty and staff now have access to 6 new MultispeQ v1.0 instruments and we are actively involving the UNZA team in the design of the new online analytical capacity, which will both lead to publications and help nucleate a phenotyping center at UNZA. In addition, two research technicians from the Common Bean Breeding National Program and two research technicians from the Wheat Breeding Program, both part of the Zambia Agricultural Research Institute (ZARI) in Zambia have received training on PhotosynQ. Over the past year, this has resulted in 9 PhotosynQ projects being created in FY 2017 and 19,783 measurements being collected on common bean and wheat. Similarly, we have provided 5 MultispeQ v1.0 instruments to Makerere University, which are available for faculty and staff to use, resulting in the initiation of 9 separate research projects in which over 14,000 measurements have been made on cowpea, groundnuts, and maize.

The irrigation capacity at the University of Zambia research farm in Lusaka, Zambia has been upgraded using supplemental Institutional Capacity Strengthening funds. Purchase and installation of irrigation equipment was completed, increasing the research capacity at UNZA to conduct drought experiments.

Finally, it is important to emphasize that all of the research accomplishments are purposely and directly connected to capacity strengthening. For example, the development of the instrumentation and PhotosynQ-guided experimental protocols were guided by the research goal of identifying the genetic bases of photosynthetic responses, but are also incorporated in the PhotosynQ platform to enable future work.

VI. Human Resource and Institution Capacity Strengthening

3. **Short-Term Training**
   (*Provide the following information for each short-term training activity completed. If a training was repeated in several places, each training must have a separate entry. Short term training is defined as a minimum of two consecutive class days or more in duration, or 16 contact hours or more scheduled intermittently.*)
   ii. Purpose of Training: Train research technicians at the Zambia Agricultural Research Institute on how to use the PhotosynQ platform to collect data from field experiments.
   iii. Type of Training: Short-term training
   iv. Country Benefiting: Zambia
   v. Estimated USAID funding for activity[1]
      a. US$ 400 for Instruction
      b. US$ 750 for Participants
      c. US$ 300 for Travel
   vi. Location and dates of training: University of Zambia (05/15/2017-05/17/2017)
   vii. Number receiving training (by gender): Two females and two males
   viii. Home institution(s): Zambia Agricultural Research Institute
   ix. Institution providing training or mechanism: University of Zambia

[1] Instruction expenses include costs directly incurred to convey knowledge or impart training, such as books, equipment, supplies, course handouts; seminar/conference/workshop registration fees and published academic tuition and fees. Participant expenses include costs directly incurred to meet personal needs and program requirements including per diem, medical exams, visa fees; health and accident insurance premium; and federal state and local taxes. Travel expenses include those costs directly incurred transporting the participant from the home country to the training country and back, as well as costs within the country.

4. Degree Training in the US or elsewhere

xxxi. Name of trainee: Susan Chipandwe
xxxii. Country of Citizenship: Zambia
xxxiii. Gender: Female
xxxiv. Host Country Institution Benefitting from Training: University of Zambia
xxxv. Institution providing training: University of Zambia
xxxvi. Supervising LIL PI: Kelvin Kamfwa
xxxvii. Degree Program: Masters
xxxviii. Field or Discipline: Plant Breeding and Seed Systems
xxxix. Research Project Title (if applicable)Estimated USAID funding for activity if not conducted in US
  a. US$ 2,000 for Instruction
  b. US$ 11,000 for Participants
  c. US$ 200 for Travel
xl. Estimated funding from other sources for activity if not conducted in US (see footnote 1)
  a. Provider of Funds
  b. US$ for Instruction
  c. US$ for Participants
  d. US$ for Travel
xli. Start Date: September, 2016
xlii. Projected/Actual Completion Date: September, 2018
xliii. Is trainee a USAID Participant Trainee and registered on TraiNet?
xliv. Training status: Active

i. Name of trainee: Isaac Osei-Bonsu
ii. Country of Citizenship: Ghana
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: CSIR-Crops Research Institute
v. Institution providing training: Michigan State University
vi. Supervising LIL PI: David Kramer
vii. Degree Program: Doctorate
viii. Field or Discipline: Plant Physiology
ix. Research Project Title: Heat Stress Effects On Photosynthesis in Legumes
x. Estimated USAID funding for activity if not conducted in US (see footnote 1)
  d. US$ for Instruction
  e. US$ for Participants
  f. US$ for Travel
xi. Estimated funding from other sources for activity if not conducted in US (see footnote 1)
  e. Provider of Funds
  f. US$ for Instruction
  g. US$ for Participants

h. US$ for Travel

xii. Start Date: August, 2015

xiii. Projected/Actual Completion Date: 2019

xiv. Is trainee a USAID Participant Trainee and registered on TraiNet?

xv. Training status: Active, indirect support

VII. Achievement of Gender Equity Goals

A critical component of accomplishing our gender equality goals is to ensure that PhotosynQ technologies are equally accessible to women and men. In FY 2017 we have made progress towards that goal by 1) training 2 female research technicians at ZARI and 2) supporting a female graduate student who is pursuing a Master's Degree in plant breeding and seed systems at UNZA using the PhotosynQ platform, with Dr. Kamfwa as her PI.

VIII. Implementation of Data Management Plan

(*Describe efforts to implement of project's Data Management Plan, including a summary of data sets that have been submitted to Open Data Access sites, including USAID DDL. Indicate your Open Data Access sites for future submissions as well.*)

The PhotosynQ platform is set up to allow for rapid communication of ideas, results, and analyses. All data collected on the PhotosynQ platform is open, making it easy for scientists from around the world to connect and share results and analyses. All data collected with the support of the Legume Innovation Lab can be easily searched on the PhotosynQ platform (www.photosynq.org) using the hashtags #LIL and #LegumeInnovationLab.

IX. Scholarly Accomplishments

(*Identify all **publications**, theses and/or dissertations, presentations, professional recognitions, awards, patents, and Plant Variety Protection Certificates that evidence scholarly accomplishments by U.S. and Host Country scientists as well as degree trainees during the performance period. Please send electronic copies of publications to the MO for sharing with USAID and include URL or DOI information where available.)*

Hoh D, Osei-Bonsu I, Cruz J, Roberts PA, Huynh BL, Tessmer OL, Savage L, Hall D, Kramer DM. 2017. Determination of cold tolerance QTLs via high throughput photosynthetic phenotyping photosynthesis. Poster, Phenome 2017. Tucson, Arizona

Hoh D, Osei-Bonsu I, Cruz J, Roberts PA, Huynh BL, Tessmer OL, Close T, Savage L, Hall D, Kramer DM. 2017.The genetic and mechanistic bases of photosynthetic cold tolerance in Cowpea (*Vigna unguiculata (L.)* Walp.) via high throughput environmental phenotyping. Poster, 43rd Annual Midwest/Southeast Photosynthesis Conference. Marshall, IN

Hoh D, Osei-Bonsu I, Cruz J, Roberts PA, Huynh BL, Tessmer OL, Close T, Savage L, Hall D, Kramer DM. 2017. Determination of cold tolerance QTLs in Cowpea (*Vigna unguiculata (L.) Walp.)* via high throughput photosynthetic phenotyping. Feed the Future Legume Innovation Lab Grain Legume Research Conference 2017. Ouagadougou, Burkina Faso.

Hoh D, Osei-Bonsu I, Cruz J, Roberts PA, Huynh BL, Tessmer OL, Close T, Savage L, Hall D, Kramer DM. 2017. Determination of cold tolerance QTLs in Cowpea (*Vigna unguiculata (L.) Walp.)* via high throughput photosynthetic phenotyping. Feed the Future Legume Innovation Lab Grain Legume Research Conference 2017. Ouagadougou, Burkina Faso.

Osei-Bonsu I, Hoh D, Loescher W, TerAvest D, Kramer D. (2017). Chlorophyll fluorescence and leaf gas exchange based phenotyping of heat stress tolerance in tepary, common bean and cowpea at the seedling and juvenile stages. Poster presented at the Phenome 2017 Conference, 10 - 14 February 2017, Tucson, Arizona.

Osei-Bonsu I, Hoh D, TerAvest D, Cruz J, Savage L, Huynh B-L, Roberts PA, Kramer D. (2017). Assessing tolerance of photosynthesis to high night temperature stress in cowpea genotypes and mapping of QTLs associated with photosynthetic traits. Poster presented at the Legume Innovation Lab Conference 2017, 13 - 18 August 2017, Ouagadougou, Burkina Faso.

Osei-Bonsu I, Hoh D, TerAvest D, Cruz J, Savage L, Huynh B-L, Tessmer O, Roberts PA, Close TJ, Kramer D. (2017). Thermo-tolerance of photosynthesis in grain legumes: mapping QTLs for photosynthetic traits in cowpea under heat stress by high throughput photosynthesis phenotyping. Presented at the 43 Midwest/Southeast Photosynthesis meeting 2017, 27 - 29 October 2017, Marshall, Indiana, USA.

Osei-Bonsu I, Hoh D, TerAvest D, Cruz J, Savage L, Huynh B-L, Roberts PA, Kramer D. (2017). Thermo-tolerance of photosynthesis in legumes: Mapping QTLs for photosynthetic traits in cowpea under heat stress. Presented at the Legume Innovation Lab Conference 2017, 13 - 18 August 2017, Ouagadougou, Burkina Faso.

TerAvest D, Mnthambala F, Kamfwa K, Yohane E, Kramer D. (2017). What do we learn from Phenotyping Tools that Bridge the Gaps between the Lab and the World? Presented at the Phenome 2017 Conference, 10 - 14 February 2017, Tucson, Arizona.

TerAvest D, Mnthambala F, Siyeni D, Ngwira A, Kramer D. (2017). PhotosynQ: Empowering Collection of Direct Crop Physiological Measurements on Smallholder Farms. Presented at the Legume Innovation Lab Conference 2017, 13 - 18 August 2017, Ouagadougou, Burkina Faso.

X. Achievement of Impact Pathway Action Plan

(At the project planning and workplan development stage, each project team prepared an Impact Pathway identifying major research outputs, users of these outputs, a vision of success, and necessary steps to achieve the vision of success. In the Impact Pathway worksheet, your project also identified strategies and an action plan to be undertaken by the project team over the 4.5 year life of the project to translate the outputs into outcomes. Please provide an update on your team's efforts in implementing the action plan and progress towards achieving the 'vision of success' as laid out in the Impact Pathway strategy. Discuss any constraints encountered and steps taken to overcome them.)

Outputs:

Output #1. Provide advanced scientific instrumentation for developing countries: The project will produce 20 MultispeQ instruments, 16 of which will be delivered to labs in Zambia and Uganda. Qualitatively, these instruments will immediately allow researchers in Africa to perform cutting edge research, enabling them to perform the work described in the proposal. In addition, we expect the capabilities of the instruments to enable researchers in HCs to initiate new research projects.

> In FY 2017, we provided 9 next generation MultispeQ v1.0 instruments to project partners at the University of Zambia and Makerere University. Between the first generation MultispeQ Beta and revised MultispeQ v1.0 instruments, faculty and graduate and undergraduate students at Makerere University and the University of Zambia have contributed significant data to the PhotosynQ platform. Specifically, at Makerere University 6 different project leads contributed 4,339 and 14,315 MultispeQ beta and v1.0 measurements, respectively. At UNZA, 2 project leads contributed 7,586 and 12,197 MultispeQ beta and v1.0 measurements, respectively.

Output#2. Capacity building by internet-enabled data and communications platform. We will develop and deliver to the community a new platform for discovering QTL's to enhance the productivity of grain legumes.

> We are currently developing a new automated data analysis pipeline within the PhotosynQ platform that will allow PhotosynQ users to rapidly connect in-field phenotyping data to genotypic data to identify QTL's in grain legumes. A beta version of this platform is expected to be completed in December, 2017.

Output #3. Capacity building through advanced phenotype-driven identification of QTLs for improving the efficiency and resilience of photosynthesis in grain legumes.

> We have successfully identified phenotype-driven QTL's using both controlled conditions in DEPI chambers and using MultispeQ under true field conditions for cold, heat and drought tolerance.

Output #4. Capacity building through education: Another essential component of the project is to enable researchers in HC to take possession of both the technolog and the educational efforts required to use it effectively. To achieve this, we plan to engage students in the process of developing and disseminating the educational materials, giving them ultimate control of the platform and process.

We have made progress towards this output goal through the following of activities: 1) training of undergraduate and graduate students at Michigan State University, the University of Zambia and Makerere University and 2) developing training videos, tutorials and educational modules that are available on www.photosynq.org so any user on the platform can learn how to use the PhotosynQ platform to answer research questions.

ANNEXES

Annex 1. Tables, Figures, and Photos Cited in the Report

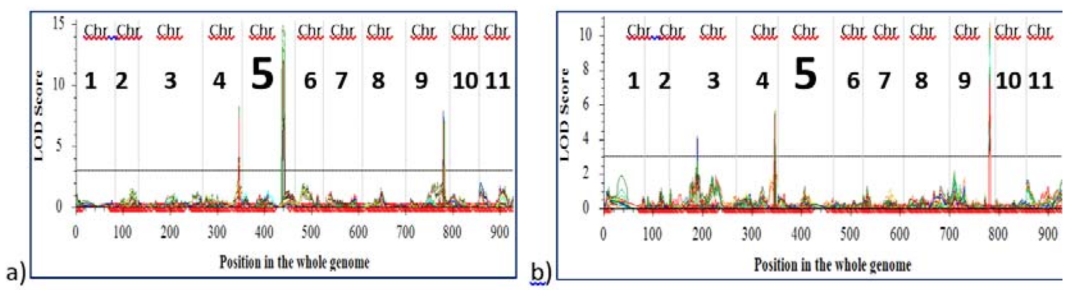

Fig 1: QTLs photosynthetic efficiency (Phi2) under a) heat stress and b) control growth conditio The QTL band on chromosome 5 is apparently specific to the heat stress whereas those on chromosome 4 and 9 are constitutively expressed.

Feed the Future Innovation Lab for Collaborative Researchon Grain Legumes

Report on the Achievement of "Milestones of Progress"

(For the Period: October 1, 2016-- March 31, 2017)

This form should be completed by the U.S. Lead PI and submitted to the MO by April 1, 2017

SO1.A2: Improving Photosynthesis in Grain Legumes with New Plant Phenotyping Technologies

0

	Abbreviated name of institutions																	
	Michigan State Univ.			U. and Zambia			Institution 3			Institution 4			Institution 5			Institution 6		
	Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved	
Milestones by Objectives	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *
	(Tick mark the Yes or No column for identified milestones by institution)																	
Objective 1	Probing photosynthetic responses in RIL and GWAS lines.																	
1.1 Map QTL's using DEPI	X	X		0			0			0			0			0		
1.2 Repeat 1.1 in field	0			0			0			0			0			0		
1.3 Biochemical analysis of 1.1 results	0			0			0			0			0			0		
1.4 Train Graduate students at MSU	0			0			0			0			0			0		
1.5	0			0			0			0			0			0		
Objective 2:	Develop a data management plan to improve the communication of ideas, results, and analysis to a large network of connected scientists.																	
2.1 Consult with USAID on privacy policy	X	X		0			0			0			0			0		
2.2 Adjust PhotosynQ privacy policies	0			0			0			0			0			0		
2.3	0			0			0			0			0			0		
2.4	0			0			0			0			0			0		
2.5	0			0			0			0			0			0		
Objective 3:	**Increase the capacity, effectiveness and sustainability of agriculture research institutions which serve the bean and cowpea sectors in the target FTF countries** **by establishing an African-USA community of networked scientists, extension agents, students and growers to address field-level research and production questions.**																	
3.1 Develop on-line exp. Design tools	X	X		0			0			0			0			0		
3.2 Create training modules	X	X		0			0			0			0			0		
3.3 Provide devices/training to Uganda	X	X		0			0			0			0			0		
3.4 Train technicians and students	0			X	X		0			0			0			0		
3.5 Repeat 1.1 experiment at U. Zambia	0			X	X		0			0			0			0		
3.6 Map QTL's in field w/ PhotosynQ	0			0			0			0			0			0		
3.7 Establsih phenotyping infrastructure at UZ	0			0			0			0			0			0		
3.8 Train field tech. and students	0			0			0			0			0			0		
3.9 Train Masters student at UZ	0			0			0			0			0			0		
Objective 4:	**write objective here**																	
4.1	0			0			0			0			0			0		
4.2	0			0			0			0			0			0		
4.3	0			0			0			0			0			0		
4.4	0			0			0			0			0			0		
4.5	0			0			0			0			0			0		
Name of the PI reporting on milestones by institution	David M. Kramer			Kelvin Kamfwa			PI name			PI name			PI name			PI name		

Name of the U.S. Lead PI submitting this Report to the MO: David M. Kramer

Signature **Date**

* *Please provide an explanation for not achieving the milestones on a separate sheet.*

Feed the Future Innovation Lab for Collaborative Research on Grain Legume
PERFORMANCE INDICATORS / TARGETS SPREADSHEET for FY 2017

Project Name: **SO1.A2: Improving Photosynthesis in Grain Legumes with New Plant Phenotyping Technologies**

Institution Name (one sheet per institution): **UNZA**

Indic. number	Output Indicators	FY 17.1 Target	FY 17.1 Revised	FY 17.1 Actual	FY 17.2 Target	FY 17.2 Revised	FY 17.2 Actual			
		(October 1, 2016 - March 31, 2017)			(April 1, 2017 - September 30, 2017)					
1	4.5.2(6) Degree Training: Number of individuals who have received degree training									
	Total number	1	1	1	1	1	1			
	Number of women	1	1	1	1	1	1			
	Number of men	0			0					
	Total number by New/continuing									
	New	1	1	1						
	Continuing				1	1	1			
2	4.5.2(7) Short-term Training: Number of individuals who have received short-term training									
	Total number	5	5	5						
	Number of women	2	3	3						
	Number of men	3	2	2						
	Numbers by Type of individual									
	Producers									
	People in government	2	2	2						
	People in private sector firms									
	People in civil society									
	People in University	3	3	3						
3	4.5.2(39) Number of new technologies or management practices in one of the following phases of development: (Phase I/II/III)									
	Phase 1: Number of new technologies or management practices under research as a result of USG assistance	1	1	1	1	1	1			
	Phase 2: Number of new technologies or management practices under field testing as a result of USG assistance									
	Phase 3: Number of new technologies or management practices made available for transfer as a result of USG assistance									

Notes:

These indicators are developed under the Feed the Future Monitoring System. Please provide 'total' numbers and also disaggregate where applicable. Just providing 'totals' will not be approved.

This table corresponds to the Feed the Future Performance Indicators data collection sheet under the FTFMS system. Where an indicator does not apply to the type of work done under the project, leave it blank.

There is additional guidance on the USAID/Microlinks website: http://agrilinks.org/sites/default/files/resource/files/FY14%20FTFMS%20Guidance_2.pdf

Improving Genetic Yield Potential of Andean Beans with Increased Resistances to Drought and Major Foliar Diseases and Enhanced Biological Nitrogen Fixation (BNF) (S01.A3)

Lead U.S. Principal Investigator and University:
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Wayne Loescher, Dept. Horticulture, MSU
James Steadman, University of Nebraska, Lincoln
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Karen Cichy, USDA-ARS, East Lansing, MI
Stanley Nkalubo – NaCRRI, Uganda
Kennedy Muimui – ZARI, Zambia

I. Abstract of Research and Capacity Strengthening Achievements

Common bean (*Phaseolus vulgaris*) is the most important grain legume consumed in Uganda and Zambia. The project has successfully identified local lines that are quicker cooking and these are being tested in on-farm trials with local producers in Uganda. Breeding programs in both countries continue to identify sources of disease resistance to many of the more serious pathogens that attack beans and are using these lines as parental material to further improve local varieties. Changes in climate are leading to less predictable rainfall patterns and the project has identified Andean breeding lines that perform better than local varieties under these conditions. Novel methodologies are being developed to screen more efficiently for cooking time and modern molecular tools have been deployed to map genomic regions that control anthracnose resistance. Genomic mapping with SNP markers and RNA sequencing has been used to pinpoint genomic regions that control anthracnose resistance, and enhanced symbiotic nitrogen fixation and candidate genes underlying these basis functions have been identified. The potential to enhance N-fixation in beans grown under low fertility conditions typical of subsistence farmers is now within the reach of local breeders. Training of future bean researchers continues to be a major objective by providing the environment to develop both scientific and leadership skills.

II. Project Problem Statement and Justification

Beans are the second most important food legume crop after ground nuts in Zambia and are a major source of income and cheap protein for many Zambians. Most of the bean crop (62%) is produced on 60,000 ha in the higher altitudes, cooler and high rainfall zones of the northern part of Zambia. Andean beans are predominant and land races are the most widely grown although a few improved cultivars are also grown as sole crops or in association mainly with maize. Bean production is constrained by several abiotic and biotic stresses that include diseases, pests, low soil fertility and drought. All the popular local landraces in Zambia are highly susceptible to pests and diseases that severely limit their productivity. This is reflected in the very low national yields ranging from 300 to

500 kg/ha that result in annual deficit of 5,000MT. To avert future food shortages and feed the growing population of 13M, there is critical need for increasing the productivity of most food crops including beans as Zambia ranks 164 out of 184 countries in the Human Poverty Index. Beans are an important crop in Uganda and are grown on over 660,000 ha of land and consumed throughout the country. Beans are a major source of food and income for the rural smallholder farmers especially the women and children. The majority of bean production in Uganda is dependent mainly on the use of inferior landrace varieties which are generally low yielding due to susceptibility to the major biotic and abiotic (drought, low soil fertility) stresses. These stresses gravely undermine the potential of the bean as a food security crop, a source of income, and as a main source of dietary protein for the majority of Ugandans. Drought affects 60% of global bean production and the severity of yield reduction depends on the timing, extent, and duration of the drought stress. The development of improved varieties and germplasm with high yield potential, healthy root systems, improved SNF with resistance to multiple diseases, and sustained or improved water use efficiency under limited soil water conditions are needed to increase profit margins, lower production costs. The project will use QTL analysis and SNP-based genome-wide association mapping to uncover regions associated with drought tolerance, disease resistance, enhanced BNF and faster cooking time.

III. Technical Research Progress

Objective 1: Integrate traditional and marker-assisted selection (MAS) approaches to combine resistances to economically important foliar diseases, drought and improved symbiotic nitrogen fixation (SNF) and assess acceptability of fast cooking, high mineral content in a range of large-seeded, high-yielding red mottled, white and yellow Andean bean germplasm for the Eastern Africa highlands (Zambia and Uganda), and the U.S.

1.1 Screen the disease nursery to different pathogens (ANT, and ALS field conditions in Uganda: Because of the complexities involves in the screening for resistance to anthracnose (ANT) and angular leaf spot (ALS), and the continued presence of these two diseases in the field throughout the year, it was deemed fit to undertake field screening of available nurseries. From the field screening local germplasm such as NABE 4, NABE 2, K131, and imported germplasm including Mexico 54, BAT 332 and PAN 72 were observed to be tolerant to ALS and the differential lines PI207262, TU, AB136 and G2333 did not show any anthracnose symptoms when screened at NaCRRI-Namulonge fields.

1.2 Complete screening for rust and CBB in Uganda: For rust, twenty-three single pustule rust isolates were collected in Uganda and inoculated on 11 rust differential bean lines and Ouro Negro (Ur-14). Six (6) rust pathotypes were identified with binary races 2-0, 4-0, 50-0, 5-1, 4-33 and 63-19. Five of the pathotypes were of Andean origin and only pathotype 4-33 was of Mesoamerican origin. The rust pathotype 63-19 showed similar pathogenic characteristics with the Puerto Rico rust race 63-19. From the screening of different germplasm, we identified seven (7) resistant lines that could be useful sources of resistance for breeding for bean rust resistance in Uganda and these included Mexico 309, CNC, P1181996, Mexico 235, Redland Pioneer, Ouro Negro and Aurora. Within the Uganda germplasm, fifteen (15) genotypes which included the landraces Nabufumbo, and Kapchorwa white, and the commercial genotype NABE2 were identified as new sources of rust resistance that would also be useful in future bean breeding efforts in Uganda. In the case of bean common bacterial blight (CBB), we used one virulent pathotype "Kawempe 1" and identified four (4) resistant bean lines with both leaf and pod resistance namely; NE2-14-8, NE17-14-29, NE14-09-78 and VAX3. In addition, we determined the mode of inheritance of CBB resistance for leaf and pod among selected Ugandan Andean genotypes. All these lines have been crossed with bean lines representing different Uganda market classes and progenies are undergoing evaluation.

1.3.1 Complete screening of the drought nursery in Uganda to intermittent drought stress: Using a drought nursery from the University of Nebraska-Lincoln comprising of 60 entries and the terminal drought screening protocol, we were able to identify seven (7) bean lines that showed drought tolerance tendencies and these include, ADP-102, ADP-41, ADP-47, ADP-61, ADP-617, ADP-660 and ADP-678. These will next undergo advance yield trial evaluation in different drought prone areas within the country. In addition, a set of eight (8) genotypes have gone through a series of multilocation evaluation trials across different agro-ecologies within Uganda. These genotypes were also made available to farmers through on-farm farmer participatory variety trials and were able to identify agronomically superior genotypes. From the evaluations, four (4) multiple disease and drought tolerant lines including SCR 26, SEN 98, SCN 11 and SCN 1 were identified as promising and have been sent for DUS/National Performance Trials (NPT). These are currently considered as candidate varieties for official release and one or two could possibly be released later in 2017.

1.3.2 Evaluation of Andean Diversity Panel (ADP) for drought stress response in Uganda.

A total of 256 ADP lines were evaluated in Uganda to assess their response to drought stress. The experiments were conducted at Mubuku Irrigation Scheme in Kasese a drought testing site in Uganda. This location on the leeward side of mountain Ruwenzori does not normally receive a lot of rain and has an irrigation facility making it a perfect site for conducting drought experiments. The second site was NaCRRI-Namulonge. The first drought experiments were conducted from November 2016 to February 2017 and included 247 ADP lines and 9 local checks. These genotypes were planted at Mubuku and NaCRRI-Namulonge under irrigated and non-irrigated conditions. However, we experienced bean fly infestation immediately after germination and this led poor plant stand. We decided to replant the drought experiment in Kasese and all experiments in Namulonge. Additional seed of the ADP lines from CIAT-Uganda was planted during the second season evaluation season from Mary 2017 to September 2017. The experiments were planted during off-season deliberately to synchronize drought stress with the reproductive stage. Drought stress was applied after flowering and water supplied to the Irrigated treatment until harvest. Data was collected on phenology traits, seed yield and yield component traits at harvest. Photosynthetic traits were measured during the pod filling stage using the PhotosynQ tool to determine the effects of reduced moisture on Photosynthetic traits. Significant variation was observed among the ADP evaluated for yield component traits and photosynthetic traits at reproductive stage. As expected, we observed highly significant and positive correlations among yield component traits, harvest index, pod harvest index and pod partition index with yield component trait. However, there were no significant correlations between yield component traits and photosynthetic traits measured using the photosynQ under rainfed conditions. Genomic regions associated with drought responses were determined using GWAS analysis and we detected significant signals for yield component traits and photosynthetic traits on Chromosomes Pv01, Pv4, Pv05, Pv06, Pv9, Pv10, and Pv11. Colocalized genomic regions were observed for yield component traits on Pv06 and for photosynthetic traits on Pv04 and Pv011. The candidate genes and their functional annotation are being explored. Using marker trait association effects, we identified accessions that carried alleles with high positive allele effects for pod weight per plant and seed weight per plant. Some of the accessions had previously been reported to have drought and heat tolerance. These genotypes are of diverse origin and market classes and could be used to improve the locally adapted germplasm for drought tolerance. In addition, 300 ADP lines were screened in the greenhouse at Namulonge to determine their response to drought stress at seedling stage. These genotypes were planted in plastic pots and watered for 21 days and withdrawn afterwards for 7 days. Data was collected on shoot traits by visual scores and Photosynthetic traits using the PhotosynQ tool during this time period. Water was then applied to check the recovery of genotypes after stress. The results of this data are being analyzed to determine the use of visual scores and photosynthetic traits to identify drought tolerant lines at seedling stage.

1.3.3 Identification of Quantitative Trait Loci (QTL) associated with drought tolerance in Portillo/Red Hawk recombinant inbred line (RIL) population: The second component of this study involved QTL mapping using Portillo/Red Hawk bi prenatal mapping population. The initially population size consisted of 113 individuals but we only evaluated 100 due to limited seed. The RIL population was evaluated in Uganda at the same locations, seasons, and conditions like the ADP. At the Mubuku Irrigation Scheme in Kasese, the RILs were evaluated for two seasons of 2016 and 2017 respectively. Meanwhile field evaluation in Namulonge was conducted in 2017 season.
Preliminary results. We identified RILs that have exhibited high yield potential under drought condition and also have the preferred market class of Uganda, these lines will be further tested for other agronomic traits and eventually recommend for release. We identified a number of QTLs for yield component traits in a number of linkage groups. These results of all three studies will form part of Isaac Dramadri PhD dissertation at Michigan State University.

1.4 Evaluate populations generated from crosses between resistance sources for angular leaf spot (ALS), rust, anthracnose, common bacterial blight, virus resistance and drought tolerance with large seeded lines with contrasting colors in Uganda: The PIC lines are Andean RILs (The PIC lines are Andean lines for drought and heat tolerance that were generated by the Dr. Diedre Fourie's bean breeding program (ARC-Grain Crop Institute, Potchefstroom) that are drought tolerant genotypes that were obtained from southern Africa. In previous trials, we made single plant selections that were followed by single row family selections. In 2017A season, preliminary yield trails were conducted. Unfortunately, they were also severely hit by drought and some of the families were lost, so out of the 416 families that were established for yield trial evaluations, only 122 have been selected. Selection was based on lines that have desirable market class traits and ability to yield over 100 kg/ha considering the drought that occurred. Sixty-nine segregant populations within different market classes (Calima, yellows, and cranberries) combining sources of multiple disease resistance and slow cooking time were advanced to $F_{2:4}$ by bulking one pod per plant and are being distributed to Uganda and Zambia for individual plant selections in each country.

1.5 Cross lines with superior disease resistance to those with shorter cooking time and high mineral bioavailability. Crosses with CBB resistant and anthracnose resistant varieties from ADP and other sources: Resistance and tolerant genotypes obtained from different screening studies for rust, ALS, anthracnose, Sclerotium, CBB, BCMV, drought and fast cooking were crossed with different Uganda genotypes including K132, NABE 15, NABE 16, NABE 17, NABE 18, NABE 19 and NABE 21, Masindi yellow, and KATB1. We were able to generate 356 different crosses and progenies arising from these crosses are at different stages of evaluation.

1.6 Advance crosses for anthracnose, bruchid and virus resistance in Uganda: Different resistances were introgressed into susceptible Uganda market class bean varieties, using identified sources of resistance. The progenies are being advanced and to date 144 promising lines have been selected to date.

1.7 Evaluation of National Nursery in Zambia

A number of both regional and national nurseries were evaluated for ANT, ALS, and CBB resistance to the three major diseases and these lines were advanced to multi-location trials while some were advanced to on farm evaluation under farmer conditions in Zambia. During the current year, the critical diseases observed on both climbers and bush types were anthracnose and common bacterial blight. A nursery of climbers from Rwanda was also evaluated for adaptation and yield. A number of lines were found to be adapted to Zambian conditions and will be further evaluated in multilocational trials, while four exceptional lines will proceed into on-farm evaluation trials. A high level of floury leaf spot was observed on these climbers. Enhanced resilience to drought was observed in the Mesoamerican gene pool, but with the challenge of climate change, it is hoped that these small seeded types will find a niche in the farming communities as they show resilient to drought. The program has advanced four small seeded lines for on-farm evaluation. The ADP was planted in two field experiments under rain-fed and irrigated conditions in Zambia in 2017. During the rainy season, there was a high incidence of CBB and ALS. This high incidence was useful for the identification of genotypes with resistance to CBB and ALS in Zambia. Identified genotypes with resistance to these two diseases, and higher productivity where crossed with Kabulangeti and Lusaka landraces, two popular landraces in Zambia. This is aimed at developing ‘kabulangeti’ and ‘yellow’ seed types that are resistant to CBB and ALS, in addition to being higher yielding. A total of six populations each with at least 400 F3 progenies were developed from these crosses, and will be planted in the field in 2018 for selections and population advancement at UNZA Research Farm and Misanfu Research Station in Lusaka and Kasama, respectively. Genome-wide association analysis was conducted using CBB data collected from the rain-fed field experiment to identify the genetic basis of the observed CBB resistance. From this analysis, genomic regions associated with CBB resistance have been identified. Samples of leaf tissue that showed symptoms of CBB were collected for culturing and isolation of the strain in the bean Breeding and Genetics Lab at University of Zambia. The isolated strain was inoculated on the ADP planted in the sreenhouse to avoid the confounding effect of phenology on CBB evaluations under field conditions. The assay is being fine-tuned and further evaluations in the screenhouse will be conducted in 2018.

1.8 Development of Kabulangeti' and Yellow seed type varieties

To develop 'kabulangeti' and 'yellow' seed type varieties for Zambia, Kabulangeti and Lusaka landraces were crossed with Uyole98, which is resistant to many races of anthracnose. Uyole98 is also resistant to ALS and Fusarium root rot. Two populations of 350 and 285 F3 progenies for Kabulangeti/Uyole98 and Lusaka/Uyole98 crosses, respectively, have been developed, and will be planted in the field in 2018 for selections and population advancement at UNZA Research Farm and Misanfu Research Station in Lusaka and Kasama, respectively. A sample of pods from the 2017 growing season that showed symptoms of anthracnose were sent to Michigan State University for isolation and race characterization. Anthracnose race 19 was identified as the causal race. Crosses of Kabulangeti and Lusaka with resistant genotypes that carry $Co\text{-}4^2$ resistance locus have since been made. Backcrosses of these crosses have been made, and marker-assisted selection for $Co\text{-}4^2$ locus is currently underway at the Bean Breeding and Genetics Lab at UNZA. Seeds of the 24 race differentials for ANT and ALS were requested from the CIAT gene bank in Colombia. The seed of these differentials was increased in the screenhouse at UNZA for the race characterization of the anthracnose and ALS pathogens in Zambia. A humidifier has been sourced from Michigan State University to help set-up the inoculation chamber at UNZA for anthracnose and ALS pathogens screening and race characterization.

1.9 Breeding for Drought Tolerance

The ADP was planted under irrigation in May 2017. A total of 275 ADP genotypes were planted in two replications under moisture stress and a control experiment of 275 ADP genotypes with two replications under no-moisture stress. These experiments were aimed at identifying Andean genotypes with tolerance to moisture stress. Identified genotypes with moisture stress were crossed with Kabulangeti and Lusaka landraces. Four populations of F2's with at least 300 genotypes for each population have been developed, and these will be planted in the field in 2018 for selections and population advancement at UNZA Research Farm and Misanfu Research Station in Lusaka and Kasama, respectively.

1.10 Breeding for Enhanced Biological Nitrogen Fixation

A population of F4:6 RILs derived from a cross of Solwezi and AO-1129-3-3A was planted at the UNZA Field station in January 2017 for evaluation for biological nitrogen fixation (BNF). Earlier, this population was evaluated for BNF in the greenhouse in two experiments in 2015 at Michigan State University. A total of 488 samples of leaf and seed tissue were collected from the field experiment at UNZA. These 488 samples were ground and shipped to University of California, Davis where they are currently being analyzed for N15 and nitrogen content. Results of this analysis will be used to map QTL for enhanced BNF under local field conditions in Zambia. Two Andean genotypes, Majesty and Inferno that were identified as high biological nitrogen fixers in earlier studies on this project, have been crossed with Kabulangeti and Lusaka landraces. These crosses are aimed at improving the nitrogen fixation abilities of the 'kabulangeti' and 'yellow' seed types that are popular in Zambia. Four populations of F3 have developed from these crosses and will be planted in the field in 2018 for selections and population advancement at UNZA Research Farm and Misanfu Research Station in Lusaka and Kasama, respectively.

1.11 Breeding for Resistance to the Common Bean Weevil

The Solwezi/A0-1129-3-3A population was also sent to University of Puerto Rico where it was evaluated for resistance to the common bean weevil, *Acanthoscelides obtectus*. Results of this evaluation have been used to identify novel QTL for resistance to the common bean weevil. Results of this evaluation showed that the common bean weevil resistance in the resistant parent could be transferred stably into other market classes. AO-1129-3-3A has since been crossed with Kabulangeti and Lusaka landraces, which are highly susceptible to common bean weevil infestation. Additionally, crosses of Kabulangeti and Lusaka, with AO-1129-3-1A and AO-1120-3-6B the other common bean weevil varieties developed at University of Puerto Rico were made in 2017. A total of six $F_{2:3}$ populations each with at least 300 genotypes have been developed from these crosses and will be planted in the field in the 2018 season. These populations are also being evaluated by a master's student at UNZA for resistance to bruchid biotype prevalent in Zambia.

1.12.1 Evaluation of Cooking Time

The cooking time of dry beans varies widely by genotype and is also influenced by the growing environment, storage conditions, and cooking method. Since this trait is experienced by consumers, influenced by many factors, and dynamic post-harvest, high throughput phenotyping methods to assess cooking time would be useful to breeders interested in developing cultivars with standardized cooking time and for food processors looking to optimize operations. The objective of this study was to evaluate the performance accuracy of a hyperspectral imaging (HYPERS) technology for predicting dry bean cooking time. Fourteen dry bean genotypes from five market classes and with a wide range of cooking times were grown in five environments over two years. Cooking time was measured as the number of minutes required for 80% of 25 stainless steel piercing rods to pass through a pre-soaked or unsoaked bean seed. Dry whole seed was hyperspectral imaged and the measurements were used to predict 1) water uptake, 2) cooking time of soaked beans, and 3) cooking time of unsoaked beans. Based on partial least squares regression models, water uptake predictions showed high sustained performance as expressed by their correlation coefficients for prediction (= 0.789) and standard error of prediction (= 4.4%). The measured cooking times for soaked beans ranged from 20 – 160 min. Cooking time predictions for soaked beans also showed sustained performance = 0.886, = 7.9 min. Cooking times were longer for unsoaked beans (ranging from 80 – 396 min) and their prediction models were less robust and accurate (r = 0.708, r = 10.6 min) (Annex 2, Table 1). The results of this study demonstrate that hyperspectral imaging technology has great potential for estimating water uptake and cooking time of dry beans in a nondestructive, simple, fast and economical way. Due to the genotypic and phenotypic variability of water absorption and cooking time in the dry bean, periodical updates of these sensing models with more samples and testing new bean accessions, as well as testing other multivariate prediction methods are further needed for improving model robustness and generalization performance.

1.12.1:
In 2017, dry beans selected for root rot resistance in Zambia were grown under terminal drought and normal conditions in Mitchell, NE. We explored the effect of drought on cooking time and water absorption for those sources. In general, dry beans under drought stress took 7 minutes longer to cook than under normal conditions. G10994, Larga Commercial, USDK-4, NE34-12-50, W16560, INIAP 414, and PI321094-D had the lowest root rot incidence. G10994 and INIAP 414 had the highest and lowest Geometric Mean, respectively. NE34-12-47 and NE34-12-50 had the lowest cooking time under DS and NS environments. G10994, Larga Commercial, W16560, INIAP 414, PI321094-D, NE34-12-28, and NE34-12-45 had the longest cooking time under both drought stress and normal conditions. These parents are being introgressed into elite Zambian germplasm. Under both drought stress and normal conditions, seed water absorption was negatively correlated with cooking time (r=-0.91** and -0.88**, respectively).

1.13 On farm evaluation for nutritional content

Common bean is an important source of protein and micronutrients and a target for iron biofortification programs. Biofortification has potential to address micronutrient malnutrition especially when plant based staples are widely grown and consumed. However, the efficacy of biofortified crops to address human malnutrition can further be improved by understanding the genotype x environment interaction for seed mineral concentration and ensuring high mineral bioavailability. Common bean genotypes with high iron and zinc concentrations, high iron bioavailability and fast cooking time phenotypes were identified through screening the Andean Diversity Panel. A subset of 15 nutritionally superior genotypes were identified and evaluated in farmers' fields along with local check genotypes in a participatory variety selection for two field seasons. Nine farmer groups each comprised of about 30 farmers participated in the field research. The growers were from districts representing three agro-ecological zones in Uganda that are important for dry bean production and consumption. A majority of the farmers preferred genotypes with upright architecture, many and longer pods, had red mottled or yellow grain color, and were high yielding especially under hostile growth conditions of too little or too much water. Seed yield across locations over the two growing seasons ranged from 400 to 2,050 kg/ha. ADP0445 from Puerto Rico was the most productive across locations and seasons. For the post-harvest preference scores 80% of the farmers selected genotypes ADP0001 and ADP0445 (red mottled), and ADP0468 and ADP0512 (yellows) as the most desired accessions. Cooking time was relatively stable across locations and yellow colored genotypes ADP0521 and ADP0512 generally cooked fastest. Based on the data from field trials, bean genotypes nutritionally superior to local checks and exhibiting good adaptation to the Ugandan bean production conditions were identified.

Objective 2: Characterize pathogenic and genetic variability of isolates of foliar pathogens collected in Uganda, and Zambia and identify sources of resistance to angular leaf spot (ALS), anthracnose (ANT), common bacterial blight (CBB), bean common mosaic virus (BCMV) and bean rust present in Andean germplasm.

2.1 Increase seed of the differentials for ANT, ALS and rust in Zambia and Uganda: To acquire enough seed and for maintenance purposes, seed for the all the different differential was multiplied for both 2016B and 2017A seasons. Currently we have on average 0.6kg seed for the surviving differential. These will be used to characterize the different anthracnose, rust and angular leaf spot disease isolates that were obtained. The twelve rust differential lines were increased in Mitchell, NE in 2017. Seed is being shipped to Uganda and Zambia for the 2017B growing season.

2.2 Complete with race characterization for ANT, ALS and Rust in Uganda: Characterization of Rust, CBB, and BCMV were complete and reports have been included in thesis for Nwokocha Blessing Adanta Odogwu (2017), Alladassi Mahulé Elysé Boris (2016), and Evarist Basil Kavishe (2017) respectively. As for anthracnose, we managed to collect 51 isolates from eight districts and these were characterized into 27 different anthracnose pathotypes. A major concern is that 9/27 pathotypes attached all twelve differentials including the highly resistant genotype, G2333. 45 different isolates of ALS have had been obtained and these are currently being characterized.

2.3 Utilize the mobile nursery protocol to determine the effectiveness of rust resistance genes in genotypes in Zambia and Uganda: The use of the mobile nursery did not work out as anticipated. We instead used the improvised humid chambers artificially set up in the screen house using cheese cloth (Fig. 2). It is here that we introduced 2-litre disposable cups containing 10-days old bean plants that had been inoculated with spores of each isolates and were kept in a humid chamber at 18-23°C and 95% relative humidity for 16 hours. The plants were then air-dried before they were transferred into the open screenhouse. The plants were observed daily for pustule sporulation and rust development until they are 15 days old. The plants were then assessed for susceptibility status. This technique was the one used to determine the pathotypes.

2.4 The project will actively collaborate with MSU and UNL NIFA projects in Zambia and Uganda and with the S01.A4 project to address issues with a variety of pathogens (that are not being directly addressed in current workplan): Through collaboration with the NIFA project, more than 500 isolates of *Sclerotium rolfsii, Pythium spp., Fusarium spp. and Rhizoctonia spp* were isolated and preserved. From these 218 isolates of *S. rolfsii* were characterized using growth rates, colony type and number of sclerotia and from these Distinct differences were observed in virulence between isolates, where isolates Sir 400, Kap 417 and Hoi 344-2 (isolates from Sironko, Kapchorwa and Hoima, respectively), were found to be the most virulent. Using these isolates, we were able to identify four (4) sclerotium resistant bean lines (i.e. ALB 171, KWP 12, KWP 17 and KWP 9) and made crosses with five (5) Ugandan market class bean varieties including, K132, NABE 19, NABE 20, NABE 21 and NABE 22 and introgress sclerotium resistance into the background of these varieties. Progenies from these crosses are currently being evaluated.

2.5. *Anthracnose race characterization, screening in Zambia:* To understand the diversity of bean pathogens in Zambia, a survey was undertaken to collect seeds from farmers just before they planted there bean crop. This was to make sure the samples were collected from seed sources being planted. Three to four weeks after the farmers planted further collection of foliar samples were collected and these collections were used to isolate and characterized the bean pathogens. The disease symptom samples collected were those of ALS, ANT CBB and rust. These are being characterized by a ZARI pathologist under the supervision of Dr. K. Kamfwa in Lusaka.

Objective 3: Use single nucleotide polymorphism (SNP)-based genome-wide association mapping to uncover regions associated with drought tolerance, disease resistance, cooking time and BNF to identify QTLs for use in MAS to improve Andean germplasm.

3.1 Develop tightly linked SNP markers for major resistance genes: To enable the identification of single nucleotide polymorphism (SNP) markers associated with rust resistance and development of markers, we conducted GWAS with a total of 76,952 SNPs on 739 individuals from nine F3 population which were screened initially with rust pathotype 63-19. The study generated fifteen (15) SNPs associated with rust resistance and of these 10 genes were annotated namely, Phvul.002G008400, Phvul.002G010100, Phvul.002G010100, Phvul.002G011500, Phvul.003G187200, Phvul.003G294300, Phvul.005G018800, Phvul.005G058200, Phvul.005G114400 and Phvul.009G034600. These enabled us design eight (8) Kompetitive allele specific PCR (KASP) markers which will need to be validated for future MAS for rust resistance in Uganda.

3.2 Fast cooking lines with high mineral bioavailablity will be grown in on farm trials and will be evaluated for farmer acceptability based on agronomic and cooking characteristics: 23 ADP lines that were evaluated for shorter cooking time, adaptability, and consumer and market preference by nine (9) farmer groups composed of 326 farmers (96 men and 230 women) in three Ugandan agroecologies. By the end of the project, seven (7) lines namely ADP 0512, ADP 0009, ADP 0001, ADP 0468, ADP 0521, ADP 0098, and ADP 0522 had been selected by farmers through PVS trial as most preferred. These lines will be advance for further evaluation and will also be crossed with other Andean Uganda market class varieties and some will be advanced through national performance trails for possible releases in the future.

3.3 Conduct sensory evaluation of lines with superior cooking time and mineral bioavailablity in Michigan, Uganda, and Zambia: In Uganda, sensory evaluations for 15 nutritionally superior genotypes with close to 100 farmers/ consumers from the three districts of Hoima, Kamuli, and Masaka/Rakai getting involved in the post-harvest preference and preparation and sensory tasting (Fig. 4). From the results four (4) genotypes namely ADP0001 (Rozi Koko) and Chijar (both red mottled), and ADP0468 (PI527538) and ADP0512 (Ervilha) (both yellows) were most preffered, while two genotypes ADP0521 (Cebo, Cela) and ADP0512 (Ervilha) that cooked faster than other lines were most preferred based on taste.

Objective 4: Develop phenometric approaches to improving the efficiencies of breeding for abiotic stress tolerance, especially drought

Much of the research focused on examining constitutive differences between drought tolerant and drought susceptible genotypes so that mechanisms contributing to drought tolerance might be discovered and further investigated. To support these efforts, research was conducted on the physiology of drought and heat stress in a selection of bean genotypes with varying degrees of stress tolerance including tepary bean. Heat stress negatively impacts the yield of common beans and prevents their cultivation in certain areas. Furthermore, under field conditions, heat stress often coincides with and exacerbates the effects of drought stress. Breeding more heat tolerant common bean cultivars would stabilize yield and open new areas to production. To support these efforts, this research examined a variety of methods for screening large numbers of bean germplasm exposed to heat stress. Tepary bean (*P. acutifolius*), a closely related species, was used as a stress tolerant check. Bean plants exposed to temperatures of 45 °C for two days showed measurable signs of heat stress. Measures of gas exchange, chlorophyll fluorescence, and oxidative stress were for the most part only affected by this high temperature and not by any temperatures below 45 °C. These measures also correlated well with visual signs of damage on leaf tissue caused by heat stress. The method was useful for screening a large group of germplasm for heat tolerance, but this heat tolerance only partially related to drought tolerance observed in the field. Plant breeders can utilize some of the methods described here to supplement field data and further characterize the stress tolerance of later generation bean lines.

Objective 5:

Institutional Capacity Building and Training continues at MSU for two doctoral students, Isaac Dramadri, and Dennis Katuuramu from Uganda. Two doctoral students graduated in FY16, Kelvin Kamfwa from Zambia, and Jesse Traub, and one MS student Grady Zuiderveen student from the US all in Plant Breeding, Genetics and Biotechnology at MSU. Thesis title listed in Annex 1. In Uganda, three postgraduate students have been engaged and trained under the project. The students are at different levels of their research as indicated below;

Ms. Blessing Odogwu; was a Phd student at Makerere University undertaking studies under the research topic "Resistance to common bean (Phaseolus vulgaris L.) rust (Uromyces appendiculatus pers. [pers.]) Unger. in Uganda". Blessing completed her studies and submitted her PhD thesis. She is currently back home teaching at the University of Port Harcourt, Nigeria. She is waiting for her thesis defense.

Mr. Alladassi Mahulé Elysé Boris was an MSc. Student at Makerere University, Uganda, where he conducted research on the "Genetics of resistance to Common Bacterial Blight disease of Common Bean (Phaseolus vulgaris L.) in Uganda". Boris was able to graduate and he is currently teaching post-graduate students at Makerere University, Kampala, Uganda.

In addition to graduate student training, we were able to train eight (8) technicians, two (2) research assistants and 10 MSc students on the use of the photosynQ for field phenotyping.
Mr. Basil Evarist Kavishe was also an MSc. Student at Makerere University, Uganda where he conducted research on the "Resistance to bean common mosaic potyviruses and its inheritance in selected Ugandan beans" Evarist completed his studies and submitted his thesis for examination. He is currently back home in Tanzania.

In Zambia, through the network of stakeholders in the bean value chain ZARI managed to train 757 (472 males and 285 females) small-scale farmers. The farmer trainings were conducted in eight districts of the three provinces where bean production is high. The farmers were trained in seed production principles, crop protection, post-harvest handling and integrated crop management. These efforts are meant to improve the availability of high quality improved bean seed in the communities.

IV. Major Achievements

The project has continued to make significant achievement towards achieving the breeding objectives especially in the area of germplasm acquisition and utilization. We have also continued with having working relationships between NaCRRI and other institutes like Makerere University, Michigan State University, University of Nebraska and in country USAID Field Mission. We have also continued our engagements with postgraduate students, farmers, NGOs and Community Based Organization (CBOs) in bean growing agroecologies in Uganda. The research achievements so far obtained are inclusive but not limited to the following:

- Through the project we have continued to identify and utilize resistance for rust, CBB, BCMV, Sclerotium root rot and drought and made crosses to introgress these resistant genes into the susceptible Uganda Andean market class bean varieties. To date 356 crosses have been made and these are being evaluated at different filial stages.
- Have identified promising drought tolerant lines SCR 26, SEN 98, SCN 11 and SCN 1 and sent then for DUS/NPT trials, hoping for possible variety by end of 2017.
- Seven (7) lines with shorter cooking time namely ADP 0512, ADP 0009, ADP 0001, ADP 0468, ADP 0521, ADP 0098, and ADP 0522 have been selected by farmers through PVS trial as most preferred.

- Identified seven (7) resistant lines to rust including; Mexico 309, CNC, P1181996, Mexico 235, Redland pioneer, Ouro Negro and Aurora.
- Determined the mode of inheritance of rust resistance for selected Ugandan Andean genotypes
- Identified resistant four (4) lines with both leaf and pod resistance for CBB including NE2-14-8, NE17-14-29, NE14-09-78 and VAX3.
- We determined the mode of inheritance of CBB resistance for leaf and pod among selected Ugandan Andean genotypes
- Identified three (3) resistant lines to BCMV including; SCR 48, SCN 9 and SCN 6.
- Determined the mode of inheritance of genes for BCMV and BCMNV resistance in Uganda Andean bean genotypes
- Identified four (4) lines with relatively good resistance to *Sclerotium rolfsii* root rot including; ALB 155, ALB 171, KWP 17 and KWP 9
- Identified 7 lines with tolerance to drought including; ADP-102, ADP-41, ADP-47, ADP-61, ADP-617, ADP-660 and ADP-678
- Designed eight (8) KASP markers associated with rust resistance that will need to be validated.
- Obtained on average about 0.6 kg of seed of each differential for rust anthracnose and ALS.
- Trained one (1) PhD and two (2) MSc. students
- We have built capacity for eight (8) technicians, two (2) research assistants and 10 MSc students on the use of the photosynQ for field phenotyping for drought.
- At least 5 NGOs were supported through training of their clients (farmers) and extension agencies
- 757 famers (472 male and 285 female) were trained in total during the period under review
- An increase in the quantity of foundation bean seed under the supervision of the bean team has been noted with 2016/17 season producing 21Mt in Zambia
- Characterization of Bean pathogens is underway and will be completed within the next 2 months
- Advancing of four drought resilient lines for On-farm evaluation in Zambia
- On-farm evaluation of climbers for adaptation to the small holder farming system
- A number of lines were found to be resistant to major bean diseases in the country
- Through this project high throughput non-destructive phenotyping tools for bean end use quality traits. Hyperspectral imaging models were developed that predict cooking time within 10 minutes of actual values (Mendoza et al., in preparation). Visible and near infrared reflectance spectroscopy (visible/NIRS, 400–2498 nm) of intact dry black beans predicted canned bean texture to R prediction values as high as 0.866 (Mendoza et al., 2017).
- Genotype by environment interaction for cooking time and seed iron and zinc concentrations were elucidated across nine on farm locations in Uganda. Wide genotypic variability for cooking time was observed (19 to 272 minutes). Two yellow beans (Cebo Cela and Elvhira) were consistently fast cooking (25 min avg.) across locations and years (Katuuramu et al., in preparation).

V. Research Capacity Strengthening

The collaborative research has enabled us to build research capacity at NaCRRI not only in terms of breeding activities but also in developing human resource capacity. In this year we were able to continue training and mentoring one PhD and two MSc students. We are also able to train a three research assistant and 5 technicians in Uganda on the use of modern technologies to capture field data and reduce on errors. Also the host country PI-Uganda, was facilitated to attend and participate in a common bean disease workshop on angular leaf spot and root rot where new insights and methods were shared on how to combat these two diseases. We also able to network with other renowned scientists and sharing research information and knowledge. For human capacity building, two short term trainings were organized for research assistants and technicians in Uganda. This was to strengthen their research capability in as far as data collection is concerned. There was training on the use of new data collection tools as part of breeding management system which tools are being utilized by the project.

We received research capacity strengthening funds to test a modified PhotosynQ for use in predicting cooking time. Unfortunately, the PhotosynQ did not work well for this purpose. All the measurements and the analysis were done in parallel with Vis/NIRS and hyperspectral, but the predictions for the hand held sensor were poor and sometimes unusual. This could be explained by the complexity of the phenomena to model in combination with the low range of spectral wavelengths (i.e., number of wavelengths) used for analysis.

VI. Human Resource and Institution Capacity Development

2. Degree Training

In the aspect of capacity building, three postgraduate students have been engaged and trained under the project. The students have all complete their studies in the areas indicated and at different levels towards graduation as indicated:

Mr. Isaac Dramadri is a PhD student at Michigan State University who is conducting his research work in Uganda on "Genomic and phenometric approaches to dissect physiological responses associated with drought adaptation within the Andean common bean genepool". Isaac his currently completing the writing up of his dissertation.

The PhD student (**Ms. Blessing Odogwu**), continued to undertake her research work on rust with the project. Through the Norman E. Borlaug Leadership Enhancement in Agriculture Program fellowship, she was also able to travel to MSU and University of Nebraska to undertake hands-on training of the use of molecular markers for screening purposes. In addition, two other MSc. students have been taken on by the project to undertake their researchers on under some of our project objectives. The first MSc. student is looking at breeding for resistance to CBB while the second student is conducting research on the BCMV disease. It hoped that the three students will make positive contribution towards new discoveries and also gain experience in research implementation. Details for the students are given below;

Student 1

i. Name of trainee: Blessing Odogwu
ii. Country of Citizenship: Nigeria
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: University of Port Harcourt, Nigeria
v. Institution providing training: Makerere University/NaCRRI
vi. Supervising CRSP PI: James Kelly
vii. Degree Program: PhD
viii. Field or Discipline: Plant Breeding and Biotechnology
ix. Research Project Title: Breeding for rust resistance in common beans in Uganda
x. Start Date: January 2014
xi. Projected Completion Date: December 2017
xii. Is trainee a USAID Participant Trainee and registered on TraiNet?: No
xiii. Training status: Active

Student 2

i. Name of trainee: Boris Mahulé Elysé Alladassi
ii. Country of Citizenship: Benin
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: University of Abomey-Calavi, Benin
v. Institution providing training: Makerere University/NaCRRI
vi. Supervising CRSP PI: None
vii. Degree Program: Masters Degree
viii. Field or Discipline: Plant breeding and seed systems
ix. Research Project Title: Genetic Analysis of Resistance to Common bacterial blight and association of candidate SNP markers of common bean (*Phaseolus vulgaris L.)* in Uganda
x. Start Date: December 2014
xi. Projected Completion Date: September 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet?: No
xiii. Training status: Active

Student 3

i. Name of trainee: Basil Evarist Kavishe
ii. Country of Citizenship: Tanzania
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: Sokoine University of Agriculture, Tanzania
v. Institution providing training: Makerere University/NaCRRI
vi. Supervising CRSP PI: None
vii. Degree Program: Masters Degree
viii. Field or Discipline: Plant breeding and seed systems

ix. Research Project Title: Resistance to bean common mosaic virus and its inheritance in selected Ugandan bean genotypes
x. Start Date: December 2014
xi. Projected Completion Date: September 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet?:No
xiii. Training status: Active

Student 4

xlv. Name of trainee (First and Last Name): Kelvin Kamfwa
xlvi. Citizenship: Zambian
xlvii. Gender: M
xlviii. Training Institution: MSU
xlix. Host Country Institution Benefitting from Training: University of Zambia
l. Supervising Legume Innovation Lab PI: James D. Kelly and Karen A. Cichy
li. Degree Program for training: Doctorate
lii. Program Areas or Discipline: Plant Breeding, Genetics and Biotechnology
liii. Thesis Title/ Research Area: Genetic dissection of biological nitrogen fixation in common bean using genome-wide association analysis and linkage mapping.
liv. Start Date: August 2008
lv. Completion Date: December 2015
lvi. Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
lvii. Training Status: graduated

Student 5:

i. Name of trainee (First and Last Name): Grady Zuiderveen
ii. Citizenship: US
iii. Gender: M
iv. Training Institution: MSU
v. Supervising Legume Innovation Lab PI: James D. Kelly
vi. Degree Program for training: Masters
vii. Program Areas or Discipline: Plant Breeding, Genetics and Biotechnology
viii. Host Country Institution to Benefit from Training: US
ix. Thesis Title/ Research Area: SNP marker development for major resistance genes
x. Start Date: August 2013
xi. Completion Date: September 2015
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training Status: graduated

Student 6:

i. Name of trainee (First and Last Name): Jesse Traub
ii. Citizenship: US
iii. Gender: M
iv. Host Country Institution to Benefit from Training: US
v. Training Institution: MSU
vi. Supervising Legume Innovation Lab PI: Wayne Loescher
vii. Degree Program for training: Doctorate

viii. Field or Discipline: Plant Breeding, Genetics and Biotechnology
ix. Thesis Title/ Research Area: Physiological differences among *Phaseolus vulgaris* cultivars differing in drought tolerance.
x. Start Date: August 2013 on Legume Innovation Funding
xi. Completion Date: January 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training Status: graduated.
xiv.

Student 7:

i. Name of trainee (First and Last Name): Isaac Dramadri
ii. Citizenship: Uganda
iii. Gender: M
iv. Host Country Institution to Benefit from Training: Makerere University
v. Training Institution: MSU
vi. Supervising Legume Innovation Lab PI: James D. Kelly and Wayne Loescher
vii. Degree Program for training: Doctorate
viii. Field or Discipline: Plant Breeding, Genetics and Biotechnology
ix. Thesis Title/ Research Area: Physiological studies on drought tolerance in Andean beans.
x. Start Date: August 2013 on Legume Innovation Funding
xi. Projected Completion Date: May 2018
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
xiii. Training Status: Active, Partial -BHEARD Fellowship from USAID Mission, Kampala.

Student 8:

xiv. Name of trainee (First and Last Name): Dennis Katuuramu.
xv. Citizenship: Uganda
xvi. Gender: M
xvii. Host Country Institution to Benefit from Training: National Crops Resources Research Institute
xviii. Training Institution: MSU
xix. Supervising Legume Innovation Lab PI: Karen Cichy
xx. Degree Program for training: Doctorate
xxi. Field or Discipline: Plant Breeding, Genetics and Biotechnology
xxii. Thesis Title/ Research Area: On farm GxE and farmer participatory evaluation of fast cooking and nutritious dry bean lines
xxiii. Start Date: August 2012
xxiv. Projected Completion Date: December 2017
xxv. Is trainee a USAID Participant Trainee and registered on TraiNet? NO
xxvi. Training Status: Active, Partial, USDA-ARS funding.

VII. Achievement of Gender Equity Goals

During the execution of the project, we did take a deliberate effort to ensure that both men and women are equitably considered in all project activities. This has been shown in all farmer activities, short and long-term training for technicians, research assistants and post graduate students. We have been able to achieve more than the 30 percent women representation that has been set during project planning. The farmer groups in Uganda involved in the participatory evaluation of beans were in most cases led by women. In addition, we focused on traits important to women including cooking time and nutritional density in this study.

VIII. Explanation for Changes
None.

IX. Self-Evaluation and Lessons-Learned
None

X. Scholarly Accomplishments – See Annex 1

XI. Progress in Implementing Impact Pathway Action Plan
The project is on track toward implementing the impact pathway. All activities listed under step 4.1 of the impact pathway have been met with the exception of disease characterization in country and those activities will be conducted during FY17. The achievements outlined above have encountered challenges mainly due to the severe drought that was experienced during the first season 2017, where we lost quite a significant number of experiments in Uganda. To solve the problem and save some of the seed, we invested in on-spot irrigation with improvised pumps and this save us some of our precious seed.

ANNEXES

Annex 1: Scholarly Accomplishments- Refereed Publications:

Ai, Y., Y. Jin, J. D. Kelly, and P. K.W. Ng. 2017. Composition, functional properties, starch digestibility, and cookie-baking performance of dry bean powders from 25 Michigan-grown varieties. Cereal Chemistry 94:400-408. doi: 10.1094/cchem-04-16-0089-r

Alladassi, B.M.E., S.T. Nkalubo, C. Mukankusi, E. S. Mwale, P. Gibson, R. Edema, C.A. Urrea, J. D. Kelly, and P. R. Rubaihayo. 2017. Inheritance of resistance to common bacterial blight in four selected common bean (Phaseolus vulgaris L.) genotypes. J. Plant Breed. Crop Sci. 9:71-78. doi: 10.5897/JPBCS2017.0644

Bruno, A. Mukankusi, M. C., Nkalubo, T. S., Gibson, P., Malinga, G. M., Rubaihayo, P., and Edema, R. 2017. Variety × environment × management interaction of diseases and yield in selected common bean varieties. Agron. J. 109:2450–2462.

Heilig, J.A. J. S. Beaver, E. M. Wright, Q. Song, and J. D. Kelly. 2017. QTL analysis of symbiotic nitrogen fixation in a black bean population. Crop Sci. 57: 118-129. doi:10.2135/cropsci2016.05.0348

Heilig, J.A., E.M. Wright, and J.D. Kelly. 2017. Symbiotic N fixation of black and navy beans under organic production systems. Agron. J.109:1-8. doi: 10.2134/agronj2017.01.0051

Kamfwa, K., D. Zhao, J. D. Kelly and K. A. Cichy. 2017. Transcriptome analysis of two recombinant inbred lines of common bean contrasting for symbiotic nitrogen fixation. PLoS ONE 12(2):e0172141. doi:10.1371/journal.pone.0172141

McClean, P.E., S.M. Moghaddam, A-F. Lopez-Millan, M. A. Brick, J. D. Kelly, P. N. Miklas, J. M. Osorno, T. G. Porch, C.A. Urrea, A. Soltani and M. A. Gruzak. 2017. Phenotypic diversity for seed element concentration in North American dry bean germplasm of Middle American Ancestry. Crop Sci. 57:3129-3144. doi:10.2135/cropsci2017.04.0244

Mendoza, F.A., K.A. Cichy, C. Sprague, A. Goffnett, R. Lu, and J.D. Kelly. 2017. Prediction of canned black bean texture (Phaseolus vulgaris L.) from intact dry seeds using visible/near-infrared spectroscopy and hyperspectral imaging data. J. Sci. Food Agric. doi: 10.1002/jsfa.8469

Mendoza, F. A., Kelly, J. D., and Cichy, K. A. 2017. Automated prediction of sensory scores for color and appearance in canned black beans (Phaseolus vulgaris L.) using machine vision. International Journal of Food Properties, 20(1), 83-99.

Odogwu, B.A., S. T. Nkalubo, C. Mukankusi, T. Odong, H. E. Awale, P. Rubaihayo, and J. D. Kelly. 2017. Phenotypic and genotypic screening for rust resistance in common bean germplasm in Uganda. Euphytica 213:49. doi: 10.1007/s10681-016-1795-y

Odogwu, B.A., Nkalubo, S., Mukankusi, C., McCoy, S., Paparu, P., Rubaihayo, P., Kelly, J.D. and Sadman J. 2016. Prevalence and variability of the common bean rust in Uganda. African Journal of Agricultural Research. 11(49), 4990- 4999. doi:10.5897 /ajar2016.11600 issn: 1991-637x.

Odogwu, B.A., Nkalubo, S. and Rubaihayo, P. 2016. Genetic analysis of resistance to common bean rust disease in Uganda. RUFORUM Working Document Series (ISSN 1607-9345) No. 14 (1): 699-705. http://repository.ruforum.org. 7x.

Padder, B.A., P.N. Sharma, H.E. Awale, and J.D. Kelly. 2017. *Colletotrichum lindemuthianum*, the causal agent of bean anthracnose. J. Plant Pathology 99: 317-330. doi: 10.4454/jpp.v99i2.3867

Rossman, D.R., A. Rojas, J.L. Jacobs, C. Mukankusi, J.D. Kelly, and M.I. Chilvers. 2017. Pathogenicity and virulence of soilborne oomycetes on dry bean (*Phaseolus vulgaris*). Plant Disease. doi.org/10.1094/PDIS-02-17-0178-RE

Traub, J., J. D. Kelly, and W. Loescher. 2017. Early metabolic and photosynthetic responses to drought stress in common and tepary bean. Crop Sci. 57:1-17. doi:10.2135/cropsci2016.09.0746

Journal article under review

Alladassi, B.M.E., S. T. Nkalubo, C. Mukankusi, H. N. Kayaga, P. Gibson, R. Edema, C. A. Urrea, J. D. Kelly and P. R. Rubaihayo. 2017. Screening of common bean germplasm for combined leaf and pod resistance to common bacterial blight disease in Uganda. Manuscript under review in Crop Breeding and Applied Biotechnology Journal.

Isaacs, K.B., S.S. Snapp, L. Butare, and J.D. Kelly. 2017. Genotype by cropping system interactions in climbing bean and maize associations in Northern Province, Rwanda. Field Crops Res. (submitted).

Kelly, J.D. 2017. Developing improved high-yielding varieties of common bean. Ch.18. In: Achieving sustainable cultivation of grain legumes (ed. Sivasankar et al) Burleigh Dodds Science Publishing (in press).

Kelly, J.D., G.V. Varner, P. N. Miklas, K. A. Cichy and E.M. Wright. 2017. Registration of ‘Cayenne’ small red bean. J. Plant Regist. (Review).

Kelly, J.D., G.V. Varner, M.I. Chilvers, K. A. Cichy and E.M. Wright. 2017. Registration of Red Cedar’ dark red kidney bean. J. Plant Regist. (Review).

Mendoza, F.A., Wiesinger, J.A., Cichy, K.A., Lu, R. and Kelly, J.D. Prediction of cooking time for soaked and unsoaked dry beans (Phaseolus vulgaris L.) using hyperspectral imaging technology. In preparation for The Plant Phenome Journal.

Odogwu, B.A; Nkalubo, S.T; and Rubaihayo, P. (2017) Yield loss associated with common bean rust in Uganda. (2017). Manuscript under review in Field Crops Journal.

Odogwu, B.A.; Yao, N.; Odeny, D.; Shorinola, ONjung’e, Nkalubo, S.T. and Rubaihayo, P 2017. SNP identification and marker assay development for high-throughput selection of bean rust resistance. Manuscript under review in PLOS ONE Journal.

Traub, J., T. Porch, M. Naeem, G. Austic, J. D. Kelly, and W. Loescher. 2017. Screening for heat tolerance in *Phaseolus* spp. using multiple methods (preparation).

Wang, W., J.L. Jacobs, M.I. Chilvers, C. M. Mukankusi, J.D. Kelly, and K.A. Cichy. 2017. QTL analysis of Fusarium root rot resistance in an Andean x Middle American RIL population. (Submitted Crop Sci.).

Presentations, Dissertations, Patents and Awards:

Poster & paper presentations

1. Traub, J.R., J.D. Kelly, and W. Loescher. Physiological components of heat and drought tolerance differences in *Phaseolus vulgaris* and *P. acutifolius. Presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
2. Dramadri O.I., S.T. Nkalubo., and J. D. Kelly. Genome Wide Association Analysis for Terminal Drought Tolerance in Andean Common Beans. *Presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso*
3. Kamfwa K., D. TerAvest, J.D. Kelly, and D. Kramer. 2017. Harnessing PhotosynQ-connected Phenotyping Technologies for Common Bean Breeding in Zambia. *Presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
4. Urrea, C.A., S. Nkalubo, K. Muimui, J.D. Kelly, J. Steadman, and E.V. Cruzado. Effect of drought on bean cooking time using germplasm selected for drought, common bacterial blight, and root rot resistance for Uganda and Zambia. *Presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
5. Nkalubo T. S., B.A.Odogwu, B.M.E. Alladassi, E. B. Kavishe, I. Dramadri, D. Katuramu, G. Luyima, K. Cichy, C. Urrea, J. Steadman and J.D. Kelly. Genetic Improvement in Uganda's Andean Bean Breeding Program. *Poster presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
6. Katuuramu D.N, J.D. Kelly, G.B. Luyima, S.T. Nkalubo, R.P. Glahn, and K.A. Cichy. Agronomic and Sensory Attributes Evaluation of Nutritionally Superior Common Bean (*Phaseolus vulgaris* L.) Genotypes with Farmers from Three Agro-ecological Zones in Uganda. *Poster presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
7. Muimui, K. K., A. L. Okello, P. Chikuma, R. Lungu. Enhancing bean productivity through community seed multiplication in Mbala and Mporokoso districts of Northern Zambia, Poster Presentation at the *Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
8. Steadman, J., B. Odogwu, S. Nkalubo, C. Mukuma, K. Muimui, J. Millhouse, and C. Urrea. Search for resistance to bean rust in Zambia and Uganda: Field and greenhouse tools. *Poster presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*

Non-refereed Publications:

1. Bornowski, N., F. A. Mendoza, and J. D. Kelly. 2017. Mapping and predicting color retention and other quality traits in black bean populations. Ann. Rep. Bean Improv. Coop. 60:151-152.
2. Vandemark, G.J., M. A. Brick, J. D. Kelly, J.M. Osorno, and C.A. Urrea. 2017. Yield gains in dry beans in the U.S. Ann. Rep. Bean Improv. Coop. 60: 183-184.
3. Steadman, J., and C.A. Urrea. 2017. Uganda trip report (Nov. 11-16, 2016). The Bean Bag. 35(1): 10 & 11.

Patents:
None

Awards:
James R. Steadman received the Meritorious Achievement Award presented by the Feed the Future Legume Innovation Lab at the Grain Legume Research Conference in Ouagadougou, Burkina Faso.
Kelvin Kamfwa received the Early Career Grain Legume Scientists Award in recognition of early career achievement in grain legume research and commitment to improving the livelihoods of smallholder farmers in developing countries. The award was presented by the Feed the Future Legume Innovation Lab at the Grain Legume Research Conference in Ouagadougou, Burkina Faso.

Thesis:
Ms. Blessing Odogw; was a Phd student at Makerere University who conducted her on bean rust disease. Blessing completed her research work and submitted her desertion entitled "Resistance to common bean (Phaseolus vulgaris L.) rust (*Uromyces appendiculatus* (Pers. Pers.) Unger.) in Uganda" for examination. She has returned to her home country Nigeria and is teaching at University of Port Harcourt, Nigeria.

Mr. Alladassi Mahulé Elysé Boris was an MSc. student at Makerere University, Uganda, and conducted research on CBB. Boris completed his research work and has already graduated. His research was entitled "Genetics of resistance to Common Bacterial Blight disease of Common Bean (*Phaseolus vulgaris* L.) in Uganda". Mr. Alladassi is currently teaching post graduate students at Makerere University.

Mr. Basil Evarist Kavishe was also an MSc. Student at Makerere University, Uganda who conducted research on the "Resistance to bean common mosaic potyviruses and its inheritance in selected Ugandan beans" Evarist has also submitted his dissertation and he is waiting for graduation.

Annex 2: TABLES

Table 1 Calibration and prediction results of cooking time [min] using hyperspectral imaging on a panel of intact dry beans for soaked and unsoaked seeds.

	UNSOAKED (From 80.1 to 147.0 min, 127 samples)					**SOAKED** (From 19.9 to 95.5 min, 122 samples)				
	Avg. Fact.	$\overline{R}_{cal}$	$\overline{SEC}$	$\overline{R}_{pred}$	$\overline{SEP}$	Avg. Fact.	$\overline{R}_{cal}$	$\overline{SEC}$	$\overline{R}_{pred}$	$\overline{SEP}$
Smooth	7	0.711	9.6	0.573	11.4 [A]	7	0.783	9.7	0.694	11.0 [E]
1Der	5	0.652	10.4	0.513	11.9 [B]	7	0.769	10.0	0.668	10.8 [C]
2Der	8	0.765	8.8	0.637	10.9 [C]	14	0.946	4.2	0.739	9.8 [F]
CWT	10	0.945	4.5	0.708	10.6 [D]	14	0.983	2.9	0.886	7.9 [G]

Smooth, 1Der, 2Der, CWT and Ratios: Smoothing, first derivative, second derivative, continues wavelet transform decomposition, respectively, combined with the two-band ratios preprocessing method.

Avg. Fact.: Average number of features required for the partial least square model after optimization

$\overline{R}_{cal}$ and $\overline{R}_{pred}$: Average correlation coefficients of calibration and prediction, respectively, over four calculations

$\overline{SEC}$ and $\overline{SEP}$: Average standard error for calibration and prediction, respectively, over four calculation

[A, B, C, D, E, F, G] Same letters in rows and columns represent no-significant differences (p-values ≥ 0.05).

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes

Report on the Achievement of "Milestones of Progress"

(For the Period: April 1, 2017 -- September 30, 2017)

This form should be completed by the U.S. Lead PI and submitted to the MO by Oct 1, 2017

Project Title: SO1.A2 Improving Genetic Yield Potential of Andean Beans with Increased Resistances to Drought and Major Foliar Diseases and Enhanced Biological Nitrogen Fixation (BNF)

Milestones by Objectives	MSU Target 10/1/17	MSU Achieved Y	MSU Achieved N*	UNL Target 10/1/17	UNL Achieved Y	UNL Achieved N*	NaCRRI Target 10/1/17	NaCRRI Achieved Y	NaCRRI Achieved N*	ZARI Target 10/1/17	ZARI Achieved Y	ZARI Achieved N*	Institution 5 Target 10/1/17	Institution 5 Achieved Y	Institution 5 Achieved N*	Institution 6 Target 10/1/17	Institution 6 Achieved Y	Institution 6 Achieved N*
Objective 1: Integrate traditional and marker-assisted selection (MAS) approaches to combine resistances to economically important foliar diseases, drought and improved biological nitrogen fixation (BNF) and assess acceptability of fast cooking, high mineral content [illegible] of large-seeded, high-yielding Andean bean germplasm for the Eastern Africa highlands (Zambia and Uganda) and US. (Tick mark the Yes or No column for identified milestones by institution)																		
1.1. Evaluation of Integrated Nursery	0			0			1		1	1	1		0			0		
1.2. Identification of resistance sources	1	1		1	1		1	1		1	1		0			0		
1.3. Crossing and backcrossing resistance sources	1	1		1	1		1	1		1	1		0			0		
1.4. Evaluation of lines for BNF	0			0			1	1		1	1		0			0		
1.5. Population development for genetic studies	0			0			1	1		0			0			0		
1.6. Screening for cooking time	1	1		1	1		0			0			0			0		
1.7. Canning evaluation of lines	1	1		0			0			0			0			0		
1.8. Evaluation of elite lines for cooking time bioavailability	0						0			0			0			0		
1.9. Assembling a Legume Innovation Lab nursery for drought tolerance (Andean and Mesoamerican). Coordinate with the SO1.A4, CIAT, PABRA [illegible]	0			1	1		1	1		0			0			0		
1.10. [illegible]	0			1	1		0			0			0			0		
1.11. Seed multiplication	0			0			1	1		1	1		0			0		
1.12. Site identification - BNF (sandy soils and low organic matter content)	0			0			0			1	1		0			0		
1.13. Field testing screening HLR lines Zambia	0			0			1			1	1		0			0		
Objective 2: Characterize pathogenic and genetic variability of isolates of foliar pathogens collected in Uganda, Zambia and identify sources of resistance to angular leaf spot (ALS), anthracnose (ANT), common bacterial blight (CBB), bean common mosaic virus (BCMV) and bean rust present in Andean germplasm.																		
2.1. Anthracnose race characterization, screening	1	1		0			1	1		1	1		0			0		
2.2. Angular leaf spot race characterization, screening	0			0			1	1		1	1		0			0		
2.3. Rust characterization, screening	1		1	1	1		1	1		0			0			0		
2.4. Common Bacterial Blight Screening	0			1	1		1		1	1	1		0			0		
2.5. Compile database of past pathogen collections	0			0			1	1		0			0			0		
Objective 3: Use single nucleotide polymorphism (SNP)-based genome-wide association mapping to uncover regions associated with drought tolerance, disease resistance, cooking time and BNF to identify QTL for use in MAS to improve Andean germplasm.																		
3.1. SNP marker development linked to major resistance genes	1	1		0			0			0			0			0		
3.2. SNP marker associated with BNF	1	1		0			0			0			0			0		
3.3. SNP markers associated with drought	0			0			0			0			0			0		
3.4. MAS for disease screening using MAS	0			0			0			0			0			0		
3.5. Phenotypic BNF and drought tolerance for genotyping	0			0			0			0			0			0		
3.6. Fingerprinting lines/populations with SNP markers	0			0			0			0			0			0		
3.7. Association mapping	0			0			0			0			0			0		
3.8. Farmer preference traits for fast cooking bean lines	0			0			0			0			0			0		
Objective 4: Focus on phenometric approaches to improving the efficiencies of breeding for abiotic stress tolerance, especially drought																		
4.1. Identify, assemble selected and small sets of physiologically contrasting genotypes from breeders, and the required tissue [illegible] e.g. Andean [illegible]	1		1	0			0			0			0			0		
4.2. Conduct and evaluate the effectiveness of imaging [illegible] of contrasting genotypes	1	1		0			0			0			0			0		
4.3. Identify differences among genotypes with contrasting responses to abiotic, heat, light, and drought stresses	1	1		0			0			0			0			0		
4.4. Maintain and continue developing [illegible]	1	1		0			0			0			0			0		
4.5. Focus on methodologies on drought stress	0			0			0			0			0			0		
Objective 5: Capacity Building																		
5.1. Graduate Student training	0			0			0			0			0			0		
5.2. Short term training for collaborators and technicians (SNP Markers application)	0			0			0			0			0			0		
5.3. Short term training of graduate students in [illegible] and bioinformatics	0			0			0			0			0			0		
5.4. Train PhD or MSc students	0			0			1	1		0			0			0		
5.5. Short term training for technicians [illegible]	0			1	1		0			1	1		0			0		
Name of the PI reporting on milestones by institution	James Kelly			James Steadman, [illegible] Stanley Nkalubo						Kennedy Muimui			Fname			Fname		

Name of the U.S. Lead PI submitting this Report to the MO: James Kelly

Signature ____________________ Date ____________

* Please provide an explanation for not achieving the milestones on a separate sheet.

Explanation for achievement NOT completed by Oct 1-2017

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes
REVISED PERFORMANCE INDICATORS / TARGETS SPREADSHEET for FY 14, FY 15, FY16, and FY 17

Project Name:S01.A3 Improving Genetic Yield Potential of Andean Beans with Increased Resistances to Drought and Major Foliar Diseases and Enhanced Biological Nitrogen Fixation (BNF)

Summary of all institutions

Indic. number	Output Indicators	FY 14 Target	FY 14 Revised	FY 14 Actual	FY 15 Target	FY 15 Revised	FY 15 Actual	FY 16 Target	FY 16 Revised	FY 16 Actual	FY 17 Target	FY 17 Revised	FY 17 Actual
		(October 1, 2013 - September 30, 2014)			(October 1, 2014 - September 30, 2015)			(October 1, 2015 - September 30, 2016)			(October 1, 2016 - September 30, 2017)		
1	4.5.2(6) Number of individuals who have received USG supported long-term agricultural sector productivity or food security training	3	0	2	3	1	3	6	6	5	3	3	2
	Total number by sex	2	0	0	6	1	3	6	6	5	3	3	2
	Number of women	1	0	0	3	1	1	1	1	1	0	0	0
	Number of men	1	0	0	3	0	2	5	5	4	3	3	2
	Total number by New/continuing	3	0	2	3	1	3	6	6	5	3	3	2
	New	1	0	1	1	0	1	0	0	0	0	0	0
	Number of women	0	0	0	0	0	0	0	0	0	0	0	0
	Number of men	0	0	0	0	0	0	0	0	0	0	0	0
	Continuing	2	0	1	2	1	2	6	6	5	3	3	2
	Number of women	0	0	0	0	0	0	0	0	1	0	0	0
	Number of men	0	0	0	0	0	0	0	3	4	3	3	2
2	4.5.2(7) Number of individuals who have received USG supported short-term agricultural sector productivity or food security training	6	0	0	12	13	28	14	14	12	15	15	1054
	Total number	6	0	0	12	13	28	14	14	12	15	15	1054
	Number of women	3	0	0	5	6	20	5	5	7	7	7	469
	Number of men	3	0	0	7	7	8	9	9	5	8	8	585
	Numbers by Type of individual	6	0	0	12	13	28	14	14	12	15	15	1054
	Producers	0	0	0	0	0	0	2	2	2	0	0	1023
	Number of women	0	0	0	0	0	0	0	0	2	0	0	460
	Number of men	0	0	0	0	0	0	0	0	0	0	0	563
	People in government	6	0	0	12	13	26	10	10	8	10	10	7
	Number of women	0	0	0	0	0	0	0	0	4	5	5	3
	Number of men	0	0	0	0	0	0	0	0	4	5	5	4
	People in private sector firms	0	0	0	0	0	2	2	2	2	5	5	5
	Number of women	0	0	0	0	0	0	0	0	1	3	3	1
	Number of men	0	0	0	0	0	0	0	0	1	2	2	4
	People in civil society	0	0	0	0	0	0	0	0	0	0	0	19
	Number of women	0	0	0	0	0	0	0	0	0	0	0	6
	Number of men	0	0	0	0	0	0	0	0	0	0	0	13
3	4.5.2(39) Number of new technologies or management practices in one of the following phases of development: (Phase I/II/III)	3	0	0	8	1	8	14	14	16	15	15	30
	Phase 1: Number of new technologies or management practices under research as a result of USG assistance	3	0	0	6	0	4	8	8	9	8	8	16
	Phase 2: Number of new technologies or management practices under field testing as a result of USG assistance	0	0	0	2	0	2	4	4	4	3	3	8
	Phase 3: Number of new technologies or management practices made available for transfer as a result of USG assistance	0	0	0	0	1	2	2	2	3	4	4	6

Notes:

These indicators are developed under the Feed the Future Monitoring System. Disaggregate where applicable. Just providing 'totals' will not be approved.

This table corresponds to the Feed the Future Performance Indicators data collection sheet under the FTFMS system. Where an indicator does not apply, leave it blank.

There is additional guidance on the USAID website: https://feedthefuture.gov/sites/default/files/resource/files/Feed_the_Future_Indicator_Handbook_Sept2016.pdf

VI. Development and implementation of robust molecular markers and genetic improvement of common and tepary beans to increase grain legume production in Central America and Haiti (SO1.A4)

Lead U.S. Principal Investigator and University:
James Beaver - University of Puerto Rico, Mayaguez, PR

Collaborating Host Country and U.S. PIs and Institutions:
Consuelo Estévez de Jensen - University of Puerto Rico, Mayagüez, PR
Timothy Porch - USDA/ARS/TARS, Mayaguez, PR
Phil Miklas - USDA/ARS, Prosser, WA
Juan Osorno and Phil McClean – North Dakota State University (NDSU), Fargo, ND
Juan Carlos Rosas - Escuela Agrícola Panamericana (Zamorano), Honduras
Julio Cesar Villatoro - Instituto de Ciencia y Tecnología Agrícola (ICTA), Guatemala
Emmanuel Prophete - National Seed Service, Ministry of Agriculture, Haiti

I. Abstract of Research and Capacity Strengthening Achievements

Conventional plant breeding techniques and marker-assisted selection were used to develop dry bean cultivars with enhanced levels of disease resistance and greater tolerance to abiotic stresses. During the past few years, the Bean Technology Dissemination project multiplied and distributed seed of improved bean cultivars developed by S01.A4 plant breeders to farmers in Central America and Haiti. A BGYMV resistant black bean will be released by ICTA in Guatemala as 'Patriarca'. The BGYMV and BCMNV resistant and drought tolerant black bean line MEN-2201-64ML from Zamorano was released in Honduras as 'Lenca Precóz'. Seed of Lenca Precoz, BGYMV and BCMV resistant red mottled bean breeding line PR0737-1 and BGYMV, BCMV and leafhopper resistant yellow bean line PR1146-138 were multiplied in Haiti. Red mottled, cranberry and pinto bean lines with BGYMV and BCMNV resistance were tested in field trials. Black bean breeding lines that combine resistance to BGYMV, BCMNV and bruchids are also ready for field testing. The ICTA bean program has begun to test breeding lines developed in Guatemala demonstrating a greater capacity to conduct research. Angular leaf spot isolates from Honduras and Puerto Rico were found to have high levels of virulence. Populations were developed to identify a molecular marker for the *Bgp-1* gene that confers resistance to pod deformation in the presence of BGYMV. Novel QTLs for resistance to angular leaf spot, halo bacterial blight and the common bean weevil were identified.

Novel sources of resistance to BCMNV in tepary bean were identified in a newly developed Tepary Diversity Panel (TDP). Tepary bean populations are under development to increase seed size, improve agronomic traits, and combine disease resistance (BCMNV, rust, common blight). Tepary adaptation trials have been conducted in Honduras, Nicaragua, El Salvador, Tanzania and Burkina Faso.

A bean research workshop was held in Honduras. Bean researchers from Central America and Haiti described research achievements and discussed future research and training

needs to promote the production and consumption of beans in CA/C. Héctor Martínez from Guatemala, Iveth Rodríguez from Honduras and Diego Rodríguez completed M.S. degree training at the UPR. Carl Didier Joseph from Haiti plans to complete M.S. degree training at the UPR in June, 2018. Carlos Maldonado from Guatemala and Lucy Lund from the U.S. are receiving M.S. degree training at NDSU. Several B.S. degree students have opportunities to work with the bean research program at Zamorano.

II. Project Problem Statement and Justification

Increased bean production during the past 30 years in Central America and Haiti has been due, in large part, to expansion of production in the lowlands (< 1000 m). The greater heat tolerance and BGYMV resistance of the small red cultivar CENTA EAC contributed to increased bean seed yield and production in El Salvador. Bean production in Guatemala and Nicaragua has expanded into more humid lowland regions whereas a significant portion of the beans in Haiti continues to be produced in the lowlands. Bean production in Africa could be expanded if lines with better lowland adaptation were developed. This Legume Innovation Laboratory project addressed several of the biotic and abiotic constraints often encountered by bean producers in the tropical lowlands.

BCMNV threatens bean production in warmer bean production regions of Mexico, Central America, the Caribbean and Africa. The recent arrival of BCMNV in the Caribbean made the selection for resistance to this virus a priority breeding objective in Haiti, the Dominican Republic and Puerto Rico. Collaborative research supported by the Legume Innovation Laboratory has resulted in the development and release of black bean cultivars and breeding lines such as DPC-40, Sankara and MEN-2201-64ML that combine resistance to BCMNV and BGYMV. Small red bean breeding lines with the same combination of resistances were developed at Zamorano. These BGYMV and BCMNV resistant black and small red bean lines are available in the event that BCMNV emerges as a threat to bean production in Central America. The availability of small red bean breeding lines with BCMNV resistance permits the field testing of this seed type in Eastern Africa.

Small red and black beans tend to have greater yield potential and heat tolerance than Andean beans. Middle American beans also tend to have greater resistance to diseases in Africa, since pathogens in this region have co-evolved with Andean beans. Increased resistance to common bacterial blight and web blight is needed for beans produced in warm and humid lowland regions such as the Petén in Guatemala. This combination of resistances may also permit increased production of beans in Central America during the first growing season when rainfall is generally more abundant and reliable. The previous Dry Grain Pulse CRSP project (UPR-1) developed Middle American and Andean bean breeding lines having adaptation to the lowland tropics and different combinations of resistance to diseases (common bacterial blight, rust, angular leaf spot, web blight and root rot) and tolerance to edaphic constraints (low N soils, high temperature). During the past five years, the Legume Innovation Lab project has used these elite breeding lines as the base for the continued improvement of beans for our target countries. Several improved black and small red bean germplasm lines and cultivars have been released in

Central America and the Caribbean. This Legume Innovation Laboratory project continued, in collaboration with CIAT, to support the bean research network activities in Central America and the Caribbean. Collaborative activities such as the regional performance nurseries helped to extend the impact of this project through the release of improved cultivars throughout the region.

In Haiti, this project tested and released red mottled, yellow and black bean cultivars with enhanced levels of disease resistance. This effort is consistent with the FtF 2011-2015 multi-year strategy in Haiti to increase the production of staples such as beans to increase food security. Yellow, red mottled and white bean breeding lines having resistance to BCMNV and other diseases are available for Legume Innovation Lab or Feed the Future projects, CIAT and National Bean Research Programs to test in Eastern Africa.

Andean bean breeding lines developed by Dr. Paul Kusolwa at Sokoine University of Agriculture have a unique combination of traits that confer a high level of resistance to bruchids. These breeding lines include the APA locus derived from *P. acutifolius* and possibly the null phaseolin trait from *P. coccineus*. These bruchid resistant breeding lines have been used as progenitors by the University of Puerto Rico bean breeding program to introgress this resistance into black, small red and white beans that also have resistance to BCMV, BCMNV and BGYMV. Evaluations have been conducted in Central America and the Caribbean to measure the durability of the resistance when exposed to different genera and ecotypes of bruchids.

The project continues to screen germplasm to identify additional sources of resistance to diseases that limit bean production in Central America and the Caribbean. For example, more resistance to ashy stem blight, caused by *Macrophomina phaseolina*, is needed to improve adaptation to hot environments such as the dry corridor in Central America and southwestern Haiti. Greater resistance to web blight, caused by *Rhizoctonia solani*, is required to increase yield and seed quality of beans produced in more humid environments such as the Petén Department in Guatemala and eastern Nicaragua. Project personnel have the expertise and experience needed to reliably phenotype the Andean and Middle American Diversity Panels and RIL populations for traits of economic importance. This has contributed to the identification and genetic mapping of new sources of disease resistance and tolerance to abiotic stress.

There are regions and/or growing seasons in Central America, Haiti and Africa that are too hot and/or dry to produce common beans. The tepary bean (*P. acutifolius*) is a viable alternative grain legume for these stressful environments. In fact, farmers on the Pacific coast of Central America and some countries of Africa already produce tepary beans on a limited scale. In addition to heat and drought tolerance, tepary bean lines with resistance to common bacterial blight, root rots, BCMV, bruchids and other important traits, such as tolerance to low soil fertility, have been identified. Resistance to BCMV, BGYMV, larger seed size and improved agronomic traits, would increase the potential adoption of tepary beans. In addition to pyramiding these traits within tepary, interspecific crosses with common bean are being used as a long-term effort to introgress useful traits between common and tepary bean. This effort represents the first systematic attempt to genetically improve cultivated tepary bean.

Bean breeders were early adopters of marker-assisted selection to identify lines with desired combinations of traits. This resulted in increased efficiency in the development of improved breeding lines. There are, however, molecular markers available for a limited number of traits. Others, such as the SAP6 SCAR marker, are only effective in a specific gene pool. Therefore, there is a need to develop new or more robust markers, particularly for traits of economic importance to bean breeding programs in the tropics. Advances in sequencing the bean genome and the use of GWAS facilitated the mapping and development of molecular markers for traits of economic importance, while breeder-friendly InDel and KASPar markers are a broadly applicable technology. This Legume Innovation Lab assisted in the development of the populations and the collection of phenotypic data needed to identify improved markers for traits such as the *Ur-11* gene for rust resistance *I* gene for resistance to BCMV and the *Bgp-1* gene for resistance to pod deformation in the presence of BGYMV. Dr. Phil McClean and Dr. Phil Miklas have lead the collaborative effort to develop improved molecular markers.

Differences and linkages between S01.A4 and other Feed the Future (FtF) Projects

- The focus of the S01.A4 project is on biotic constraints and abiotic constraints in the <u>tropical</u> <u>lowlands</u>. Successful bean cultivars need resistance/tolerance to <u>both</u> types of constraints.
- Other FtF projects are focused on beans in the highlands of Africa and Guatemala. Given the expected trends in climate change, breeding beans for adaptation to the lowlands may help to identify bean germplasm with improved adaptation to future highland environments.
- The focus of the S01.A4 project is on <u>Central America/Caribbean</u> vs. Africa. It should be noted that the exchange of breeding lines among FtF projects has been mutually beneficial.
- Genomic research, development of molecular markers and the sharing of breeding strategies and breeding populations are common links among projects.

III. Technical Research Progress

Objective 1. Genetic improvement of common and tepary beans for Central America and Haiti.

Development, testing and release of improved common bean cultivars

Conventional plant breeding techniques and marker-assisted selection were used by Legume Innovation Lab scientists to develop common bean cultivars and breeding lines with enhanced levels of disease resistance and with greater tolerance to abiotic stresses. Plant breeders have focused on the most important biotic and abiotic constraints in lowland (< 1000 m) bean production regions in Central America and Haiti. The bean research program at Zamorano coordinated the regional testing of small red and black bean breeding lines. The University of Puerto Rico coordinated the development and testing of Andean beans in the Caribbean. These trials were conducted in collaboration with national bean research programs and CIAT. Promising lines were tested throughout Central America and the Caribbean, including countries that did not participate in this Legume Innovation Lab project. Testing lines in different countries provided more information concerning the potential performance of the lines and expanded the potential impact of the research supported by the Legume Innovation Lab. In addition to yield trials, field trials have been conducted to screen bean lines for resistance to specific diseases such as angular leaf spot, powdery mildew, ashy stem blight, web blight, efficiency for biological nitrogen fixation and high temperatures. Testing sites have been chosen to produce reliable results for screening for specific traits.

Table 1. Bean trials distributed to Central American and Caribbean Bean Research Network collaborators during 2016-2017.

Trial name	Small red	Small black	Countries
Regional bean adaptation nursery (VIDAC)	42 entries + 2 checks	55 entries + 2 checks	Costa Rica, El Salvador, Guatemala, Honduras, Haiti, Nicaragua, Panama, Puerto Rico_
Regional yield and adaptation trial (ECAR)	14 entries + 2 checks	14 entries + 2 checks	Costa Rica, El Salvador, Guatemala, Honduras, Haiti, Nicaragua, Panama
Bean variety validation trial (COVA)	8 entries + 2 checks	8 entries + 2 checks	Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua_
Regional angular leaf spot trial (ERMAN)	14 entries + 2 checks		Costa Rica El Salvador, Guatemala, Honduras,
Regional web blight trial (ERMUS)	14 entries + 2 checks		Costa Rica, El Salvador, Guatemala, Honduras,
Biofortified bean trial (AGROSALUD)	8 entries + 2 checks		Costa Rica, El Salvador,

		Guatemala, Honduras, Nicaragua, Panama
Regional high temperature trial (ERSAT)	22 entries + 2 checks	Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, P Rico___
Regional drought trial (ERSEQ)	22 entries + 2 checks	Costa Rica, El Salvador, Guatemala, Honduras, ___
Regional low fertility trial (ERBAF)	22 entries + 2 checks	Costa Rica, El Salvador, Guatemala, Honduras, Puerto Rico

Greater tolerance to abiotic stress

Although disease resistance is the primary focus of this Legume Innovation Lab project, the performance of bean breeding lines is evaluated in low fertility soils. Honduras has an ideal site for the evaluation of lines for adaptation to low P soils. Puerto Rico has good sites for screening beans for performance in a low N soil, root rot resistance and different levels of drought and high temperature stress. These sites were used to evaluate the performance of bean breeding lines derived from recurrent selection for increased BNF and/or selected for greater nitrogen use efficiency. These sites were inoculated with efficient *Rhizobium* strains to allow indirect selection for enhanced BNF. Several S01.A4 Co-Principal Investigators also participate in the Feed the Future Innovation Lab for Climate Resilient Beans. This extends the range of environments that promising bean lines can be screened for adaptation to abiotic stress. Results from the BASE 120 trials conducted at Isabela, Puerto Rico helped to identify bean breeding lines with superior nodulation scores and root rot resistance.

Bruchid resistance

Red kidney bean breeding lines developed by Dr. Paul Kusolwa (Sokoine University of Agriculture) and Dr. Jim Myers (Oregon State University) were screened in Puerto Rico for bruchid and virus (BCMV and BCMNV) resistance. One of the bruchid and virus resistant lines, AO-1012-29-3-3A, was formally released (Kusolwa et al., 2016). Dr. Kusolwa used AO-1012-29-3-3A as a progenitor to transfer BCMV and BCMNV (I + $bc\text{-}1^2$) resistance into breeding lines for Tanzania. The same line has been used to introgress resistance to bruchids into different commercial seed types (black, small red, red mottled, light red kidney). A laboratory screening technique developed at the University of Puerto Rico was used to screen the RILs for bruchid resistance. QTL analyses were used at NDSU and at the University of Zambia to explore the genetic basis of resistance to the common bean weevil derived from a cross with AO-1012-29-3. During the past year, seed increases of black bean breeding lines that combine bruchid and multiple virus resistance were conducted in Honduras. On-farm trials will be conducted during the second growing season of 2017 to test the effectiveness of bruchid resistance with seed storage methods normally utilized by farmers in Honduras. Another black bean line with bruchid and multiple virus resistance was selected by ICTA bean researchers for evaluation in multi-location performance trials in Guatemala.

Evaluation of bean diversity panels and identification of new sources of disease resistance

The Middle American (MDP) and the Andean Diversity (ADP) panels were screened in Central America and the Caribbean for specific traits. Performance of the Middle American Diversity Panel was evaluated in low N environments in Central America and in Puerto Rico in 2016. The Middle American Diversity Panel has been screened in Puerto Rico for resistance to ashy stem blight. A screenhouse trial was planted in Juana Diaz, PR, to evaluate the reaction of the trial BASE 120 to *Macrophomina phaseolina* isolate Mph-JD2. A suspension of inoculum of the pathogen was applied at the base of the bean plants. Disease severity was assessed at maturity based on the CIAT (1-9) scale and stem microsclerotia colonization. Lines that showed resistance to Mph-JD2 were: BAT 477, BIOF 2-106, SB-754, SER 78, SXB-405, SJC 730-79.

Genetic Improvement of Tepary Beans

Although tepary bean has high levels of abiotic stress tolerance, it is susceptible to viruses such as BGYMV, BCMV, and BCMNV and to other diseases. In order to expand the potential use of tepary bean in abiotic stress prone regions, a primary focus of this project has been to incorporate newly identified resistance in tepary accessions into the ARS-TARS tepary breeding program, and to initiate the introgression of virus resistance from common bean into tepary bean. Advanced breeding lines developed from these and previous breeding efforts were increased and shared with the collaborators for testing in Tepary Adaptation Trials (TAT). New tepary breeding lines were generated from crosses between promising large and round seeded genotypes from the Tepary Diversity Panel (TDP) and breeding lines selected for disease and abiotic stress tolerance. These breeding lines are initially tested through a shuttle breeding program with M. Brick at Colorado State University. This effort has focused on seed size/shape, drought and heat tolerance, and CBB and bruchid resistance in PR; and on photoperiod insensitivity, broad adaptation, rust resistance, and yield in Colorado. The superior lines were considered for entry in the TAT. TDP accessions with higher efficiency for biological nitrogen fixation (BNF) were also identified in the thesis work of Ana Vargas. In 2016, over 10 accessions were identified in the Tepary Diversity Panel (TDP) with resistance to the NL3 strain of BCMNV. These 10 accessions were tested against strains representing different pathogroups of BCMV and BCMNV at Prosser, WA to evaluate for broad resistance, and one wild accession was found to have resistance to more than one strain. Previously, TDP lines with tolerance to BGYMV and to ALS were identified in Honduras. Resistance to these diseases and BNF efficiency is being pyramided in the breeding program through a separate approach involving the generation of bulk breeding populations (bulked up to the F_4 generation) and testing in Puerto Rico and Honduras. Individual plant selections from these bulk breeding populations were completed under abiotic stress in Puerto Rico in 2016 and under high levels of BGYMV pressure in Honduras in 2017. The tepary breeding lines with tolerance to BGYMV and with resistance to BCMV will be pyramided in subsequent efforts. Superior lines from the breeding program have been included in the TAT trials and tested in the host countries including Burkina Faso, Tanzania, Angola, Honduras, Haiti, and the U.S. for potential future release. Lines in these adaptation trials have been identified with tolerance to low fertility, leaf hopper, and CBB, and with broad adaptation. Through collaboration with the FtF-ARS Legumes Project and the Climate Resilient Bean Project, a RIL population, from the cross G40001/G40022, was genotyped and evaluated for a number of seed quality, agronomic, disease, phenological, and physiological traits in trials conducted under heat, drought, and non-stress conditions and a number of novel QTL have been identified. In addition, the TDP has been genotyped using GBS, the diversity of tepary analyzed, and the nutritional composition of tepary compared to common bean in a recent publication, thus providing valuable information for current and future breeding efforts.

Objective 2. Develop and implement robust molecular markers for disease resistance genes

This project leveraged results from the USDA Common Bean Agricultural Project and the USDA/DOE/JGI common bean sequencing project. The BeanCAP project developed a suite of ~3000 InDel markers distributed across all common bean chromosomes. These markers are codominant and designed to be functional in labs with a simple set of equipment and reagents (Thermal Cycler, gel chambers, and UV lamp). The power of these markers is that they are simple to implement and thus completely portable in all laboratories and are amenable to multiplexing with suites of markers. Multiplexing reduces the cost of genotyping an individual line. The release of the common bean whole genome assembled sequence allows for precise localization of each of these markers. The final key element that facilitates this project is the development, over the last fifteen years, of markers (mostly SCARS) that are linked, from 0-5 cM, to important target disease genes. While useful, there has been some difficulty in the portability of these markers from one laboratory to another. SCAR markers all have unique experimental conditions that preclude multiplexing, and > 5% recombination reduces effectiveness due to recombination between marker and target gene. In addition, these SCAR markers don’t work across different market classes or genetic backgrounds. Contrastingly, most InDel markers developed at NDSU are market class specific, which will facilitate their use and increase their reliability.

Identify genetic materials for marker evaluation

Potential targets for improved marker development include:

- Bean golden yellow mosaic virus resistance genes and QTL (*bgm*, SW12, *Bgp*)
- Bruchid resistance genes (*Arc2, Arl3, PHA* and *aAI3*)
- BCMV and BCMNV (*I, bc-u, bc-3, bc-1*^{2})
- Bean rust (*Ur*-3, *Ur-4, Ur-5, Ur-11*)
- Common bacterial blight (SAP-6, Xa11.4, Pv07-QTL)

For each of these targets, we will adopt the same procedure. First, we will search the published literature and communicate personally with breeders, geneticists, and pathologists in both Legume Innovation Lab projects to identify genetic materials with contrasting phenotypes (resistance, susceptibility) for the specific disease. These could be genetic populations or a collection of lines with known phenotype that can then be used for the identification of closely linked indel markers. Project personnel have already participated in the evaluation of the Middle American and Andean Diversity Panels for reaction to several different diseases.

Development of InDel markers

- DNA will be isolated from genetic populations or collections of lines with known phenotypes.
- The physical locations of target genes or markers will be identified using sequence information. If the sequence information is poor or unavailable, the specific marker will be cloned and sequenced.
- <u>InDel marker selection</u>: Once the location of the marker is determined, it will then be compared to the InDel database to discover InDel markers that straddle the physical location of the marker. Those InDel markers will be used in PCR amplification to determine which one acts as a definitive marker that is unambiguous in its predictive power. If several markers have equal predictive power, then the one that will best work as a multiplexing marker will be selected. Legume Innovation Lab bean breeding programs in Guatemala, Honduras, Ecuador, Tanzania and Uganda have the facilities and technical expertise needed to immediately adopt the use of InDels for marker-assisted selection.

Objective 3. Institutional capacity building

Formal and informal training activities were conducted to enhance the capacity of host country bean research programs to develop and release superior-performing bean cultivars that increase production or reduce losses in the target countries. The M.S. degree students received a broad range of training in conventional and molecular plant breeding techniques so that they can assume roles of leadership in bean research programs in the target countries. Informal training of technicians should improve the reliability and quality of bean research conducted in host countries.

A workshop was held in Honduras in July 2017. Bean research accomplishments in Central America and the Caribbean were presented. Participants discussed future bean research and training needs in Central America and the Caribbean. This workshop was conducted in collaboration with the Feed the Future (FtF) Innovation Lab for Climate Resilient Beans and the FtF USDA-ARS Legume Project. The workshop presentations were posted on the FtF USDA-ARS Bean Research Team Web Site.

IV. Major Achievements

Development, testing and release of improved bean cultivars

- In Guatemala, the ICTA bean research program plans to release a black bean cultivar with superior yield potential and resistance to BGYMV and BCMV as 'Patriarca'.
- The BGYMV, BCMV and BCMNV resistant black bean line MEN2201-64ML was released in Honduras as 'Lenca Precoz'. Seed this early maturity and drought tolerant line was multiplied in Haiti in preparation for release as a cultivar.
- The black bean cultivar 'Sankara' combines resistance to BGYMV, BCMV, and BCMNV. When planted at higher altitudes, Sankara has earlier maturity than the black bean cultivar 'DPC-40'. Phil Miklas found XRAV-40-4 to be well adapted to the Western U.S. bean production region. There is interest among Western U.S. seed producers to market high-quality bean seed in Central America and the Caribbean. The project collaborated with the USDA-ARS FtF project to contract the production of seed of 'Sankara' in Idaho during the summer of 2016. Approximately, 11,000 kg of seed were shipped from Idaho to Haiti in time for the 2016-2017 winter growing season. The National Seed Service distributed seed to bean producers with access to irrigation including long-term collaborators such as Zamni AgriKol and AKOSAA
- 'Beseba' is a photoperiod insensitive and heat tolerant lima bean landrace originally collected by the National Seed Service in Haiti. Beseba was observed to have BGYMV resistance in nurseries planted at Zamorano. During the past year, F_3 lines were selected at Isabela, Puerto Rico from the cross 'Beseba x Sieva'. The goal is to develop a determinate, white-seeded lima bean cultivar adapted for production in the Carribean. Seed of the F_3 lines will be sent to Dr. Raphael Colbert and Mr. Gasner Demosthene for further evaluation and selection in Haiti.
- Recombinant inbred lines from the crosses 'A-429 x Morales' and 'A-429 x Tío Canela 75' were phenotyped in Honduras for degree of pod deformation in the presence of BGYMV. The seed of the phenotyped RILs will be sent to Dr. Phil Miklas to identify a molecular marker for the dominant gene *Bgp-1* that confers resistance to pod deformation in the presence of BGYMV.
- Determinate black bean lines with *bgm*-1, *I* and *bc-3* virus resistance genes were developed at the UPR. These early maturity lines may be useful for avoiding terminal drought or for production at higher altitudes.
- Several of the most recent cultivar and breeding line releases (Sankara, MEN 2201-64 ML, PR0806-80, AO-1012-29-3-3A) possess combinations of genes (I + *bc-3*) o (I + $bc\text{-}1^2$) that confer resistance to BCMV y BCMNV.
- Web blight continues to be a serious bean disease in the humid tropics such as the Petén region of Guatemala. A total of 644 lines from different bean research programs were screened over a period of two years (2015 and 2016) at Isabela, PR for reaction to web blight. Thirty-seven lines were identified that had mean web blight scores over years ranging from 2.4 to 4.5 based on the CIAT 1-9 evaluation scale.

Some of the web blight resistant lines produced commercial seed yields > 1,500 kg/ha. Some lines such as Amadeus 77 have susceptible leaf reaction but yielded well with a low % of damaged seed. These results suggest the desirability of evaluating leaf reaction, seed yield and % damaged seed.

- During the summer of 2017, these heat tolerant and web blight resistant lines and 450 F_7 lines from the 3rd cycle of recurrent selection for web blight resistance were evaluated in field trials planted at Isabela, Puerto Rico and Zamorano. Breeding lines were identified that had low levels of web blight infection at both locations and good yield potential under moderately hot conditions. These lines were included as entries in a ERMUS trial that will be distributed to collaborators in CA/C.
- Small red and black bean breeding lines were developed at Zamorano (ALS 0532-6, ALS 0531-41, ALS 0532-38 y NIC 604-29) with durable resistance to ALS. These lines, which combine Mesoamerican (*Phg-2*) and Andean (*Phg-1*) genes for ALS resistance and genes for resistance to BGYMV and BCMV, were evaluated in the regional ALS trial (ERMAN). These sources of resistance were used in Puerto Rico to develop white bean breeding lines with enhanced levels of resistance to ALS.
- Three QTL for ALS resistance were identified in Puerto Rico in the Andean RIL population 'CAL 143 x Rojo'. Two of the three QTL (ALS2RC y ALS11RC) had not been reported in previous studies.
- Sources of different genes for resistance to ALS were sent to NDSU to conduct 10X sequencing of genomic libraries. The goal is to develop breeder-friendly molecular markers linked to important clusters of resistance genes of common bean.
- Sister lines from the cross 'PR1212-5 x PR0737-1' were screened at Isabela, PR for powdery mildew resistance over two growing seasons. Bulk segregant analysis will be used to identify QTL in this Andean bean population associated with powdery mildew resistance.
- Ashy stem blight caused by *Macrophomina phaseolina* (Mp) is a serious bean disease, especially in hot and dry environments. Bean lines were screened for reaction to ashy stem blight using a virulent isolate of MP from Juana Díaz, PR. The screenings, which were conducted twice, identified the following lines to have intermediate levels of resistance: BAT 477, MER 2212-28, PR 1147-3, TARS-MST1 and TARS-LFR-1. No lines were identified to have high levels of resistance to this isolate of Mp.
- Evaluations were conducted in the field and greenhouse to screen F_2 and $F_{2:3}$ lines from the cross 'PR0313-58 / VAX 6' for reaction to the common bacterial blight (CBB) strain *Xap* UPR 3353. Segregation patterns suggest that in this population two dominant genes confer resistance to CBB. Seed of the lines phenotyped for reaction to CBB will be sent to Dr. Phil Miklas to screen for putative markers associated with resistance.
- During the past few years severe damage caused by leafhoppers (*Empoasca kraemeri*) has been observed on beans in Honduras, Guatemala, Haití and Puerto Rico. The damage is generally more severe in hot and dry environments. The yellow bean breeding line, PR1146-138 released in 2016 (Beaver et al., 2016. J. Plant Reg. 10: 145-148), has resistance to BGYMV, BCMV and leafhoppers. Black bean lines were identified in Damien, Haiti that expressed good levels of resistance to leafhoppers. PR1146-138, Morales, EMP 299 have been used as parents to introgress

leafhopper resistance into common bean breeding populations for Central America and the Caribbean.

- Dr. Porch conducted trials in Puerto Rico in collaboration with project S01.A3 to screen bean populations for reaction to leafhoppers. These trials led to the identification of QTLs associated with leafhopper resistance in common bean (Brisco et al., 2014. Crop. Sci. 54: 2509-2519). Several pinto bean lines from these genetic studies were confirmed to have leafhopper resistance in multiple trials in the Dominican Republic, Puerto Rico, and Haiti, with resistance sourced from EMP 507.
- Several tepary lines from the TAT also showed resistance to leaf hoppers, QTL were identified for leafhopper resistance in the G40001/G40022 RIL population in a single trial, and lines from the RIL were identified with high levels of leafhopper resistance and multiple disease resistance.
- Rust resistant white bean breeding lines were used as parents to introgress high levels of rust resistance into black beans. DPC-40 and XRAV-40-4 were used as parents to ensure that progeny from these crosses will also have multiple virus resistance. F_5 black bean lines with good agronomic type were selected from these populations. These lines were screened during the second growing season of 2015 at Zamorano for resistance to rust. Previous research has found rust races in Honduras to have high levels of virulence. This effort should lead to the development of black bean lines that combine multiple virus resistance and the *Ur-4, Ur-5* and *Ur-11* rust resistance genes. The most promising lines will be included as entries in regional performance trials for Central America and the Caribbean.
- The yellow bean breeding line, PR1501-162 with good agronomic traits and commercial seed, was screened using molecular markers and found to combine the *bgm-1* allele and the SW12 QTL for resistance to BGYMV, the *I* allele that confers BCMV resistance and the SAP6 QTL for resistance to common bacterial blight. Other yellow bean breeding populations were developed that should combine genes for resistance to BGYMV, BCMV and BCMNV. The performance of these lines will be evaluated in Haiti and Puerto Rico during the upcoming year.
- Pinto beans gained popularity in Haiti after this market class was imported as food aid. Consumers note that pinto beans have a shorter cooking time than other seed types used in Haiti. During the past year, we multiplied seed of advanced generation lines that have the *bgm-1* allele and the SW12 QTL for BGYMV resistance and the *I* and *bc-3* alleles for resistance to BCMV and BCMNV. The lines have commercial pinto seed type and many have an erect growth habit. These lines were evaluated in trials in Haiti and Puerto Rico. These pinto lines should segregate for the *Ur-11* gene so special attention was given to select lines that did not develop rust symptoms. Because Durango race beans have performed well in Eastern Africa, the performance of the pinto lines were evaluated in Tanzania in collaboration with the USDA-ARS FtF bean research project. A few of the pinto lines expressed high levels of disease resistance and good seed yield potential when tested in Mbeya, Tanzania.
- The performance of red mottled and cranberry bean lines with commercial seed type and resistance to BGYMV, BCMV and BCMNV were evaluated in Puerto Rico and Haiti. Seed of these and other promising lines from the UPR were sent to Mr. Isaac Dramadri for evaluation in Uganda and Dr. Kelvin Kamfwa for evaluation in Zambia.

Dr. Miklas sent a BCMNV resistant Kablanketi breeding line to Dr. Kamfwa in Zambia.

- Advanced generation black bean lines from Puerto Rico that were identified to possess the *bgm-1* gene for resistance to BGYMV and the *I* and *bc-3* genes for resistance to BCMV and BCMNV were tested in Haiti, Guatemala and Puerto Rico. Many of these lines have progenitors with heat tolerance and resistance to common bacterial blight and web blight. A few of these lines expressed less damage from leafhoppers in Damien, Haiti and Jutiapa, Guatemala although many bean lines in neighboring trials were severely damaged. Black bean lines with resistance to BGYMV, BCMV, BCMNV and rust were selected for in San Jerónimo, Guatemala by ICTA researchers. Dr. Raphael Colbert and Mr. Gasner Demosthene selected lines for further evaluation in Haiti.
- IICA personnel reported that the black bean variety ICTA ZAM, that has a shiny seed coat, is acceptable to consumers in Guatemala. ICTA ZAM has resistance to BGYMV, BCMV and web blight and was identified by ICTA researchers to have superior performance in more humid regions such as the Petén region of Guatemala. ICTA ZAM is expected to be released in Guatemala during the upcoming year.
- The virulence patterns of *Pseudocercospora griseola* isolates from Honduras and Puerto Rico were studied. One isolate from Honduras was virulent to all of the ALS differential lines (race 63-63). The virulence of *Phaeoisariopis griseola isolate* ALS-9029-JD2 from Juana Diaz, PR and isolate ALS-900-ISAD from Isabela, PR was determined by inoculating 76 bean lines of the BASE 120 trial in two different screenhouse trials. The only bean genotypes resistant to both isolates were G 21212 and SER 125 with disease severity scores below 3 and no synnemata emerging after 24 hours of leaf incubation under humid chamber conditions. Lines with moderate resistance to the same isolate were ALS 0532-6, TARS HT-1, TARS MST-1, BNF 1205-31, RCB 593, SEF 14, SEF 15, PR1418-15, PR0806-81, NCB 280, SER 16, FNB 1210-48, SER 118, PR1165-3, SB 747, SB 757 and BFS 29. Important sources of resistance for the two isolates from Juana Diaz and Isabela in Puerto Rico were identified.

Greater tolerance to abiotic stress

- INTA and CENTA researchers reported that the black bean line MEN-2201-64ML from Zamorano had superior performance under drought conditions in Nicaragua and El Salvador. This line was also selected for further evaluation in Haiti based on its performance during the dry season. In addition to drought tolerance, MEN-2201-64ML was selected for resistance to BCMV, BCMNV and BGYMV. This Legume Innovation Lab project supported on-farm testing and seed multiplication of MEN-2201-64ML in Haiti and Guatemala and other Central American countries where drought is a frequent constraint to bean production. The NSS in Haiti multiplied seed of this line during the summer of 2017 to distribute to farmer groups in November. This line has been recently released in Honduras as the cultivar ‘Lenca Precoz’.
- The small red bean breeding line IBC-301-204, selected at Zamorano for resistance to BGYMV, BCMV and tolerance to low fertility, was released in Nicaragua as ‘INTA Centro Sur’.

- The small red bean breeding line RS 901-6, selected at Zamorano for earliness, resistance to BGYMV, BCMV and tolerance to drought and the highly preferred 'Rojo de Seda' commercial grain type, was recently released in Nicaragua as the cultivar 'Rojo Jinotega'.
- The small red bean breeding line SJC 730-79, selected at Zamorano for resistance to BGYMV, BCMV and tolerance to drought and high temperatures was released by CENTA in El Salvador as the cultivar ´CENTA EAC´.
- Small red and black breeding lines were selected at Zamorano from the second cycle of recurrent selection having greater nodulation, plant growth, seed yield, and resistance to BCMV and BGYMV. The most promising lines were distributed to collaborators in Central America for field evaluation in diverse conditions. Greater nodulation in the low N field (0.08 % N), soil: sand benches (0.06% N) and plastic pouches (nodulation speed) was obtained with *Rhizobium tropici* (CIAT 899) and *R. etli* (CIAT 632) strains.
- Mesoamerican bean breeding lines were identified that combine good yield potential with superior nodule numbers in low N soils. ICA Pijao, IBC-301-204, FBN-1203-47 had superior nodule numbers when inoculated in sand benches with a mixture of *R. tropici* strain CIAT 899 and *R. etli* strain CIAT 632 and in BASE 120 field trials conducted in Puerto Rico over a period of three years.
- Many of the best performing entries in BASE 120 trials conducted in low N soils at Isabela, Puerto Rico are breeding lines and cultivars developed by S01.A4 project breeding program. Most of these lines also possess resistance to BGYMV and BCMV.
- The UPR cooperated with project S01.A3 in the evaluation of a RIL population for biological nitrogen fixation (BNF) at Isabela Puerto Rico. Breeding lines with superior BNF and a QTL associated with seed yield at Isabela, Puerto Rico were identified (Heilig et al. 2017. Crop Sci. 57: 1: 118-129).
- Six Andean and six Mesoamerican bean lines were identified at Zamorano that demonstrated a differential reaction when inoculated with different strains of *Rhizobium*. These lines were used to develop a set of differentials for biological nitrogen fixation in common bean that is being tested. The differentials can be used to monitor *Rhizobium* populations in the field and can lead to the identification of strains with superior biological nitrogen fixation.

Bruchid resistance

- Rojo' backcross lines selected in collaboration with Paul Kulsolwa at Sokoine University and Jim Myers at Oregon State University combine resistance to bruchids [*Acanthoscelides obtectus* (Say)] and the *I* and *bc-1*^{2} genes that confer resistance to BCMV and BCMNV. AO-1012-29-3-3A yielded as well as USLK-1 and 'Badillo' in trials conducted in Puerto Rico. This breeding was released as improved germplasm (Kusolwa et al., 2016).
- The 'Rojo' backcross lines were used as parents to develop Andean and Middle American lines with bruchid resistance. Black, red and white bean lines were developed that combine resistance to bruchids, the *bgm-1* gene for resistance to BGYMV and the *I* and *bc-3* genes for resistance to BCMV and BCMNV. Seed of

bruchid resistant black bean lines were sent to Honduras, Guatemala and Haiti where they have been evaluated for adaptation and for resistance to local eco-types of bruchids. A Zamorano student evaluated lines selected in Puerto Rico for bruchid resistance. The lines were infested with a Honduran ecotype of *Zabrotes subfasciatus* (the Mexican bean weevil) and found to be resistant. ICTA researchers confirmed the resistance of lines from Puerto Rico after screening with two ecotypes of *A. obtectus* and one ecotype of *Zabrotes subfasciatus* from Guatemala. These results help to confirm that the bruchid resistance will be effective over a broad geographical region and will suppress the development of both of the genera of bruchids that can cause major post-harvest losses in Central America and the Caribbean.

- Many lines selected for bruchid resistance were found to possess the molecular markers developed by Dr. Paul Kusolwa for alpha amylase and phyto-haemagglutinin. These markers, however, did not account for all of the phenotypic variability associated with the bruchid resistance. One of the parents of the 'Rojo' backcross lines has the recessive null phaseolin allele. We are exploring, in collaboration with the USDA-ARS FtF project and Dr. Jim Myers, the possibility that the null phaseolin trait may contribute to bruchid resistance.
- The low frequency of F_4 breeding lines with high levels of resistance to weevils (< 10%) in several different populations suggests that, in addition to the complex APA locus, there are other genetic factors associated with resistance to the common bean weevil. The UPR obtained from Dr. Kelvin Kamfwa a recombinant inbred line (RIL) population that segregated for resistance to bruchids. The RILs are derived from the cross 'Solwezi x AO1012-29-3-3A'', a bean landrace variety from Zambia, and AO-1012-29-3, a breeding line with resistance to common bean weevil. During the past year, we phenotyped the RILs for reaction to bruchids. Dr. Kamfwa conducted a QTL analysis for bruchid resistance and found significant QTL peaks on chromosomes Pv04 and Pv10.
- The ICTA bean research program has generated several populations from crosses between sources of resistance to bruchid and major diseases. Seed of two bruchid resistant black beans were increased at Zamorano. This seed will be used to evaluate the bruchid resistance of these lines using seed storage practices of Honduran farmers.

Evaluation of bean diversity panels and identification of new sources of disease resistance

- The virulence patterns of *Pseudocercospora griseola* isolates from Honduras and Puerto Rico were studied. One isolate from Honduras was virulent to all of the ALS differential lines (race 63-63). The most virulent isolate from Juana Díaz Puerto Rico was race 63:39. This high level of virulence points to the need to pyramid genes for ALS resistance. Molecular markers SH-13 (*Phg-1*), SN02 (*Phg-2*) and E-ACA/M-CTT330 (G10474 dominant gene) were used at Zamorano for marker-assisted selection. Resistance in the field was confirmed using highly virulent races of the ALS pathogen. The small red bean line ALS 0532-6 and a black bean line ALS 0546-60 combine resistance to multiple viruses (BGYMV and BCMV), high yield potential and commercially acceptable seed type were evaluated in validation trials in Central America. ALS resistant white bean breeding lines were developed for Puerto Rico using sources of resistance from Zamorano.

- In collaboration with the USDA-ARS FtF project, association mapping of the response to *Macrophomina phaseolina* in the Andean Diversity Panel was conducted. Results from field screening identified a small group of lines in the ADP with resistance to ashy stem blight. Regions on Pv03, Pv09, and Pv11 were significant for charcoal rot resistance in the association mapping analysis.
- Isolates from a root rot nursery in Isabela were identified as *Rhizoctonia solani* (Rs), *Fusarium solani* (Fs) and *Pythium ultimum* (Pu). Inoculation tests were conducted with each fungal pathogen. Interspecific line INB 835 and TARS-LFR1 were found to be resistant to Rs. ADP 518, ADP 508 and ADP 475 were the Andean bean lines with the highest levels of resistance to Rs. Tepary beans inoculated with Fs did not develop symptoms. In contrast, common beans showed reddish lesions on the hypocotyl and browning of the tap root. The lines ADP 475, ADP 518, ADP 269 and LFR-1 had only small reddish lesions on the hypocotyl (disease scores ≤ 3). These results suggest that Rs and Fs independently produced hypocotyl and root rots.
- The Mesoamerican Diversity Panel (MDP) and a set of the Andean Diversity Panel (ADP), resistant to ALS in South Africa, were evaluated for their response to ALS in a trial at Zamorano, HN in collaboration with the FtF-USDA project. Resistant genotypes were identified for breeding efforts in both panels.
- In an attempt to identify a set of differential genotypes for *Macrophomina phaseolina* (Mp), a screenhouse trial was established to evaluate the response of common bean, tepary and interspecific (common bean x tepary bean) bean lines to Mp isolate Mph-01-JD. TARS-MST1, DOR 364 and BAT 477 were resistant to the isolate.
- The Haitian landrace lima bean variety 'Beseba' expressed a high level of resistance to BGYMV in trials conducted at Zamorano. This allows this lima bean to be planted near common bean without risking the spread of BGYMV.

Genetic Improvement of Tepary Beans

- Tepary bean breeding lines are being developed that should combine virus resistance with superior agronomic and seed traits and resistance to other diseases such as common bacterial blight and rust.Through the USDA-FtF project and a USDA Postdoc, the Tepary Diversity Panel (TDP) composed of 314 accessions was developed and genotyped with SNP markers using GBS. This represents the first comprehensive genotyping of all currently available tepary accessions between the USDA and CIAT collections. This panel has been evaluated for a number of different traits including agronomic traits in the field under abiotic stress, and CBB, BNF, and response to NL3 inoculation and GWAS has identified QTL of key traits of interest.
- In collaboration with the USDA-ARS FtF project, UPR graduate student Ana Vargas identified tepary bean accessions from the TDP that show necrotic and resistant reactions when inoculated with the NL-3 isolate of BCMNV. This resistant reaction was confirmed with ELISA for over 10 genotypes. These accessions were tested at

ARS-Prosser with multiple strains and one wild accession was found to have resistance to more than one strain. BCMV and BCMNV are currently major constraints to tepary bean production.

- GWAS analysis of the TDP identified two loci for resistance to the NL3 strain in tepary bean. Efforts to develop KASPar markers for these loci are underway.
- Recombinant Inbred Line (RIL) populations were developed and evaluated to identify genes and molecular markers for BCMV resistance. One of these RIL populations showing a necrotic response to NL3 inoculation is being genotyped using Genotyping-by-sequencing (GBS), phenotyped using visual scoring and ELISA, and QTL analysis will subsequently be completed.
- A second RIL population, G4001/G40022, was evaluated in multiple trials for a number of abiotic, biotic, agronomic and seed quality characteristics. Iveth Rodriguez, a Masters student with the LIL project, completed QTL analyses identifying the first QTL for a number agriculturally important traits in tepary bean consistent over multiple trials.
- Single plant selections for tolerance to BGYMV and resistance to BCMV are being advanced with the goal of pyramiding this resistance to both pathogens in future efforts. .
- Tepary adaptation trials have been conducted in Honduras, Guatemala, Nicaragua, El Salvador, Tanzania and Burkina Faso. A set of eight tepary lines were evaluated in the Guatemalan “dry corridor” by 100 farmers in collaboration with Bioversity International and CATIE under the methodology massive participatory evaluation. The project has recently requested black seeded tepary lines.
- In collaboration with USDA-ARS FtF project, 12 Interspecific hybrid *Phaseolus acutifolius/Phaseolus vulgaris* INB lines were evaluated in a replicated field trial with inoculation of *Bradyrhizobium* USDA 3254. A non-inoculated control and Nitrogen treatments were included. In addition to that a local check “Verano”, TARS-LFR1 and a non-nodulator line ‘G51496A’ were inoculated with *Rhizobium tropici* CIAT 899 strain. An average of 25 nodules were recorded for line INB 835 and six nodules for line INB 826. The average for line Tepary 1 was 1.5 nodules and for TARS-LFR1 26 nodules.
- Interspecific hybrids between the common bean (*Phaseolus vulgaris* L.) and the tepary bean (*Phaseolus acutifolius* A. Gray) were nodulated by different rhizobia; a slow growing *Bradyrhizobium* sp. and a fast growing *Rhizobium* spp. Elite strains of *Bradyrhizobium* (USDA 3254) and *Rhizobium tropici* (CIAT 899) were studied for their ability to nodulate effectively in interspecific hybrids. The experiment was arranged in a split plot design with inoculation of the combination of both strains, a control without inoculation and a NPK treatment in the main plot. The small plot consisted of common beans: ‘Verano’, LFR-1, TARS-Tep 23, TARS-Tep 32 and the Interspecific hybrids: INB-817, INB-848, INB 817 and INB-835. The experiment was established in Juana Diaz with a population of 1×10^2 *Bradyrhizobium* and 1×10^4 *Rhizobium* per gram of soil. The experiment was replicated four times. Six weeks after sowing nodulation and plant biomass were evaluated and at maturity seed grain yield was measured. Ten nodules were isolated in Yeast-Mannitol-Agar with bromotymol blue from each treatment to differentiate bradyrhizobia and rhizobia based on growth rate and acid production. The hybrids and the common beans

differed in nodule numbers from the tepary beans. More than 90 percent of the nodules that were isolated from the hybrids resulted in a fast growing rhizobia. In contrast, the isolations from the tepary bean nodules were from a slow-growing bradyrhizobia. The lines LFR-1, INB-809 and INB-826 were outstanding in nodule numbers. All non-tepary bean genotypes had higher values than the tepary beans for nodulation. INB-809 was superior in nodulation followed by LFR-1, Verano, INB-826, INB-835, INB-848 and INB-817. The inoculated treatment was different from the NPK treatment and the control in terms of nodule numbers, independent of the presence of soil rhizobia. Root dry weight was higher for INB-809 and LFR-1 compared to the other genotypes. Grain weight differences between treatments suggested that inoculation increased seed yield and INB-817 was superior to the other genotypes. The nodules isolated in media produced fast growing rhizobia and produced acidity in the media that was consistent with the cultural characteristics of *Rhizobium tropici.*

- A collaborative tepary bean genome sequencing consortium is being formed with Hudson Alpha, NDSU, Michigan State Univ., and USDA-ARS. The goal of this effort will be to produce the first reference genome of *Phaseolus acutifolius* using the parent of the RIL population, G40001, as the reference genotype. The tepary genome will lead to the identification, characterization of the genetic basis of factors that allow tepary beans to be more tolerant to abiotic stresses such as heat and drought for the improvement of both tepary bean and common bean.

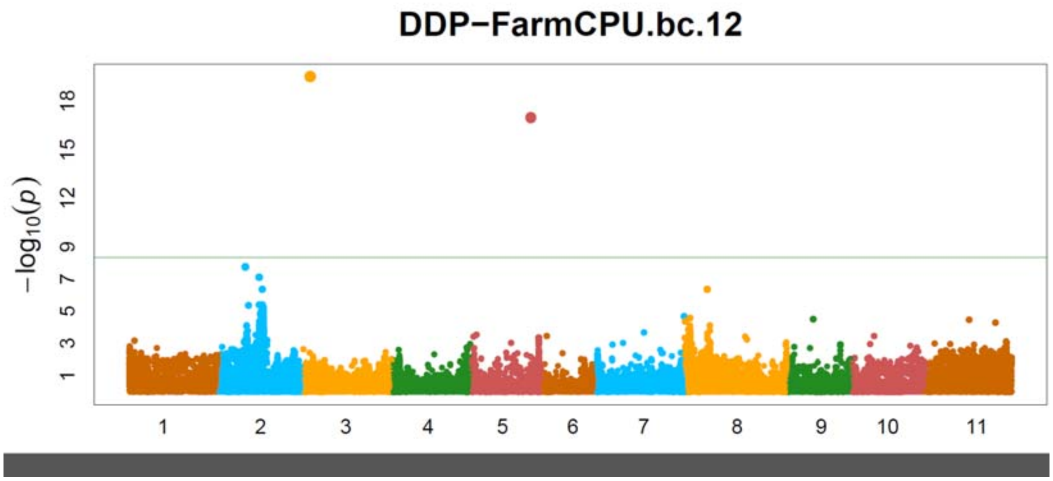
Development of molecular markers for traits of economic importance

BCMV, halo blight and BGYMV resistance

New SNP-based markers for MAS of the *I* gene that confers resistance to BCMV have been developed and are being used for indirect selection for this resistance in our breeding program and by CIAT. Meanwhile a candidate gene for *I* has been identified. Primers spanning the genomic region containing this gene are being used to sequence the gene in resistance and susceptible lines in order to develop gene-based markers and to provide the molecular tools for eventual cloning of the gene. For GWAS, more than 1000 lines representing three diversity panels – Andean, Durango, and Snap bean, were phenotyped for reaction to NL-3 strain to detect presence of the *I* gene and were genotyped with available SNP data sets possessing approximately 25,000 (Porch lab), two million (McClean lab), and 30,000 (Porch/Hart lab) SNPs, respectively. The Durango and Snap bean diversity panels were also screened with NL-8 strain. The GWAS for 200 Durango lines with reaction to both NL-3 and NL-8 strains of BCMNV with 2 million SNPs enabled fine mapping of the recessive *bc-1*^{2} gene and discovery of the genomic location for the *bc-u* gene (Fig. 1). The GWAS peak for *bc-1*^{2} is located between two candidate genes which are being sequenced for more in depth analysis. This finding of the *bc-u* gene was unexpected and supports the power that GWAS analyses can have for detecting and fine mapping epistatic genes. SNP-based markers for detection of *bc-u* have been developed and are in the process of validation in $F_{2:3}$ progenies which thus far have yielded promising results. The *bc-u* gene can be critical because it is required for expression of *bc-1*^{2}, *bc-2*^{2}, and *bc-3* genes in the absence of the *I* gene.

Being able to detect the *bc-u* gene with markers enables more precise characterization and genotyping of resistance to BCMV and BCMNV and will facilitate mapping and development of markers for the elusive *bc-2*^{2} locus. For example presence of *bc-u* as detected by these SNP-based markers seems to enhance the resistance response of *I* + *bc-1*^{2} materials to the NL-3 strain of BCMNV.

Figure 1. Manhattan plot detecting *bc-1*^{2} (on chromosome Pv03) and *bc-u* (on Pv05) genes.



A global collaboration (S01.A4; ARC-South Africa; Warwick University, UK; and Starke Ayres Seed Company) was sparked by a presentation by Andy Tock, a Ph.D. candidate from University of Warwick, Wellesbourne, UK, at the Pan African Legume conference in Zambia. His presented results on mapping halo bacterial blight resistance to Race 6 complimented our unpublished results. Together these collaborative results encompassing linkage mapping in four RIL populations and GWAS of 400 ADP lines in the field have revealed new genes and QTL for halo blight resistance on chromosomes Pv04, Pv05 and Pv10. SNP-based markers are in development and have been requested by CIAT recently to address a critical need for deploying halo blight resistance in Ethiopia.

The presence of the 5398 SNP chip enables rapid development of linkage maps with dense marker coverage for QTL discovery. We are revisiting an old RIL population Dorado/XAN 176 from UPR-breeding program (1992) that was sparsely populated with RAPD markers but nonetheless was used to discover and generate markers for the SAP6 QTL for common bacterial blight resistance and the SW12 QTL on Pv04 for resistance to BGYMV resistance. Both resistance-linked RAPD markers were converted to SCAR markers and have been widely used for MAS. The SW12 marker has been used widely by CIAT, the UPR, Zamorano and other programs for breeding beans resistant to BGYMV. The Dorado/XAN 176 RIL population was re-genotyped with the 5398 SNP chip to develop a denser linkage map to contribute to ongoing efforts by S01.A4 and CIAT researchers to develop more tightly-linked breeder-friendly markers for QTL conditioning resistance to BGYMV. Better markers for MAS of resistance QTL is considered a critical need for breeding for high levels of resistance to BGYMV because of recent severe outbreaks of the disease in Central America. The new Dorado/XAN 176 linkage map revealed that a QTL on Pv07 had greater effect on resistance to BGYMV than the previous QTL on Pv04 flanked by the SW12 marker (Fig. 2). This Pv07 QTL was validated in a CIAT RIL population DOR 476/Sel1309 which we re-genotyped with the 5398 SNP chip as well. This effort also revealed a novel QTL on Pv08 that interacted with the *bgm-1* gene to provide a greater level of resistance to BGYMV. The Pv07 QTL cosegregates with the *Bct-1* gene which confers resistance to *Beet curly top virus*.

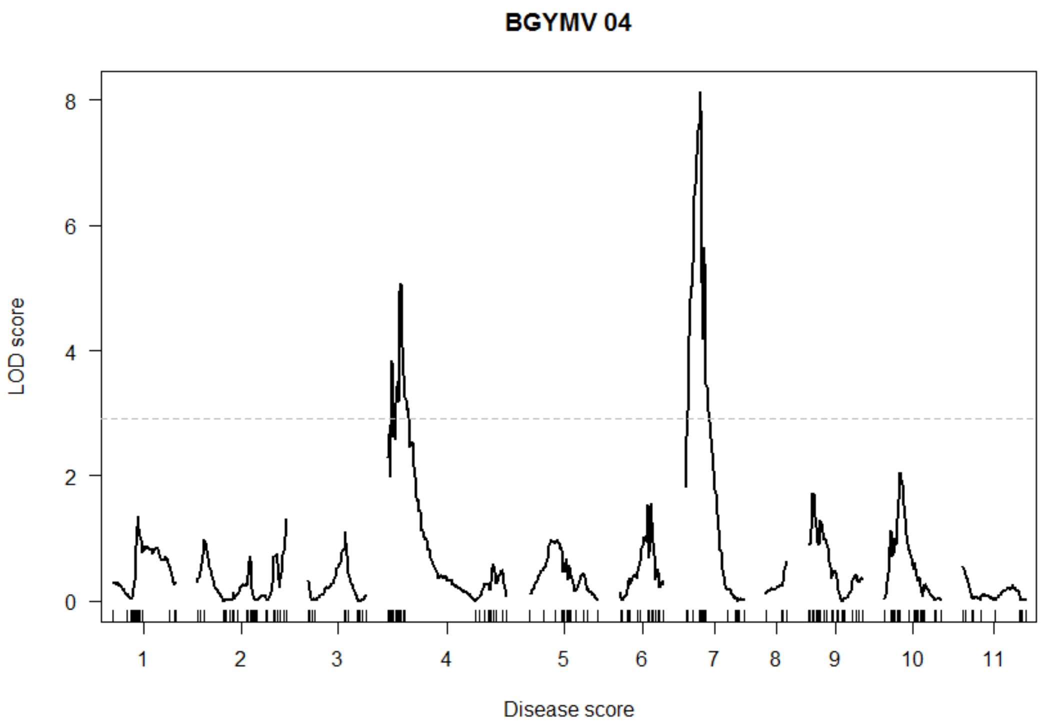


Figure 2. QTL for resistance to BGYMV detected on Pv04 (associated with SW12 marker) and Pv07 (associated with *Bct-1* gene) in the Dorado/XAN 176 RIL population re-genotyped with 5398 SNPs.

. Populations are under development at Zamorano that segregate for the dominant gene *Bgp-1* that confers resistance to pod deformation in the presence of BGYMV. Individual F_5 plants were selected at Zamorano for normal and deformed pods. $F_{5:6}$ plant rows will be screened for BGYMV resistance during the upcoming growing season. The data will be used by Dr. Phil McClean at NDSU to identify a molecular marker for this important gene for resistance to BGYMV.

Bruchid resistance

A collaborative breeding effort among Paul Kulsolwa (SUA, Tanzania), Dr. Jim Myers (Oregon State University) and Dr. Jim Beaver (University of Puerto Rico) resulted in the development of breeding lines in which the arcelin (ARC or ARL)-phytohemagluttin (PHA)-alpha-amylase inhibitor (AAI) locus (collectively known as the APA locus) from tepary accession G40199 was introduced. This locus is presumed to be the source of bruchid resistance and results in significantly reduced seed storage damage by the common and Mexican bean weevil. A molecular analysis of these lines and the tepary source of resistance was initiated by Ms. Lucy Lund, a graduate student of Dr. Phil McClean (North Dakota State University). A series of primers were designed across the three genes within the APA locus. The goal was to search for any molecular difference that distinguished resistant and susceptible lines. Seed of the RIL population from the cross 'AO1012-29-3-3 x Solwezi' from Dr. Kelvin Kamfwa that was screened in Puerto Rico for resistance to bruchids was sent to Dr. Phil McClean to identify candidate markers for resistance genes.

When data from the alpha-amylase inhibitor (α-AAI) amplification was analyzed, it was discovered that the products differed by 45bp, and that the polymorphism was completely diagnostic between the resistance source, the resistant lines, the two susceptible recipient lines and the two susceptible checks. That difference is depicted shown in Figure 3. Sequence analysis of the PCR products revealed that the 45bp difference resulted in the deletion of the lectin domain, a domain that is common to many LegB genes.

Figure 3. Amplification of common bean genotypes with primers designed to the alpha-amylase gene from the APA locus. The first four lanes are the Middle American resistant lines PR1464-1 and PR1464-6 and the Andean resistant lines AO1012-29-3-1A and AO1012-29-3A. The next four susceptible lines are: XRAV-40-4 and Rojo, the recipient parents, and Verano, and Badillo, two standard susceptible checks. The last lane is line G19833, the genotype used to develop the common bean reference genome sequence. The upper band is 275bp and the lower band is 230bp.

Multiple clones from the fragment generated by amplifying each of the resistant lines were sequenced to determine if the original source of resistance contained a single or multiple copies of the AAI gene. From that analysis it was determined that at least two copies of the gene existed for each line, and that each copy had unique sequence signatures. Additionally, the two copies were separated (at the amino acid sequence) using neighbor-joining phylogenetic tree analysis. That tree is show in Figure 4.

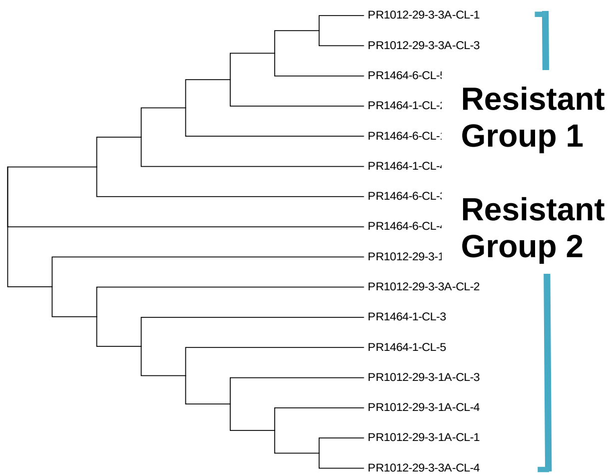


Figure 4. Neighbor-joining tree based on the amino acid sequence data for the four bruchid resistant lines developed by introgressing the resistant phenotype from tepary bean G40199. Two distinct groups of sequences are noted.

Given that the arcelin, and not the alpha-amylase locus, is thought to be the causative protein associated with resistance, a sequence analysis of multiple clones of arcelin-specific amplification products was performed. This study focused on the four resistant lines, the tepary source, and other tepary lines. To date, all of the sequence data has been collected and analyzed. We now know that the common bean genome consists of multiple LegB genes, genes with the lectin domain such as the members of the APA locus. One question of concern was if the APA locus genes were distinct from the other LegB proteins. The answer from the neighbor-joining phylogenetic analysis is yes, they form a unique cluster distinct from the members of the APA locus. That is noted in Figure 5. Also observed was that the arcelin sequences were distinctly different from the phytohemagluttin (PHA) and alpha-amylase inhibitor (AAI) proteins. These later two proteins formed a cluster among themselves. Furthermore, the arcelin sequence data formed two distinct clusters. Sequence analysis demonstrated that the tepary donor G40199 contains two distinct classes of arcelin sequences, two sequences that are indeed related (because of their relationship to only each other, and not to the other lectin containing genes). What was yet to be determined is if these two clusters actually map in the same vicinity in the genome of the tepary source, and thus also in the recipients from the introgression effort. To address this question, a RIL population derived from the cross ‘Solwezi x AO-1012-29-3-3’ provided by Dr. Kelvin Kamfwa. AO-1012-29-3-3 contains the tepary introgression for bruchid resistance. The primer pair that defined the 45bp size difference was used. The correlation between the resistance and polymorphism was not definitive, although mapping data by Dr. Kamfwa showed a resistance peak on Pv04, the chromosome where the APA locus is located.

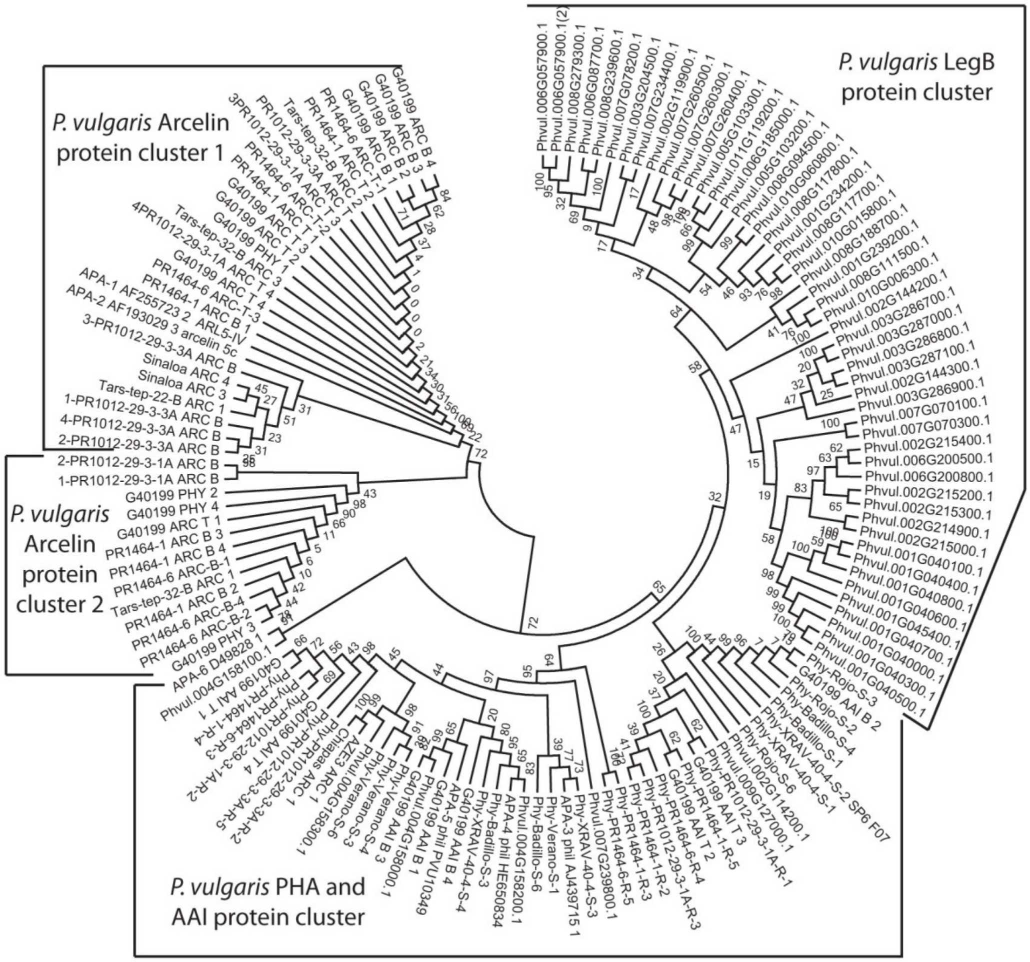


Figure 5. Neighbor-joining tree of *P. vulgaris* arcelin (ARC), PHA (phy; phytophaemaglutin), α-AI (AAI), and other *P. vulgaris* leg B domain containing proteins identified by a Pfam analysis of the amino acid sequences of the protein. The tepary (*P. acutifolius*) arcelin proteins are designated as "Tars-tep" sequence.

Bean rust resistance

At the distal end of chromosome Pv11 of common bean is located a large cluster of coiled-coil, nucleotide-binding site, leucine-rich (CNL) repeat genes (n~50). CNL genes have been shown to act as dominant resistance genes in many other host-pathosystems. In addition, many resistance specificities are located at this locus. Principal among those are the bean rust resistance genes *Ur-3*, *Ur-6*, and *Ur-11*. Because of their importance, developing highly functional molecular markers linked to these loci has been a goal for years. Dr. McClean's group, along with Dr. Phil Miklas (USDA/ARS, Prosser WA) and Dr. Talo Pastor Corrales (USDA/ARS, Beltsville) have collaborated in a molecular marker development effort.

Dr. Pastor Corrales screened 301 members of the Middle American Diversity Panel (MDP) to assess their response against bean rust races that can discover *Ur-3* and *Ur-11* specificity. Previously, Dr. McClean's group had placed the Ur-3 resistance gene in the interval 50.63 – 50.68 Mb on Pv11. 811 F2 plants were scored, and mapped with several SNP markers selected from the 50.63 – 50.68 Mb interval defined by the GWAS analysis.

Table 1. Genetic analysis of the UI 114 x C-20 F_2 population with indel and SNP markers associated with the *Ur-3* resistance locus of common bean. The F_2 data represents the number of recombinants in a population of 811 individuals.

Ur3 Marker V2.0 Pv11 Positions	# Recombinants
50,549,756	3
50,557,492	3
50,567,470	2
50,612,732	0
50,615,957	0
50,616,063	0
50,631,529	0
50,634,865	0
50,638,985	0
50,657,864	0
50,684,143	0
50,711,016	2
50,755,552	4
50,766,742	4
50,791,702	5
51,499,870	9

The data clearly places *Ur-3* between 50,567,470 and 50,711,016 Mb on Pv11. This is the most accurate positioning currently available for the position. Importantly, there are eight markers that co-segregate with the Ur-3 locus that are ready for implementation in breeding programs.

Similar efforts are underway, but not as advanced, for *Ur-6* and *Ur-11*. For *Ur-6*, a F_2 population of ~2000 individual is ready for screening with race 47 (uncovers the *Ur-6* resistance specificity). Additionally, the MDP will be screened also in the next year and a similar analysis will be performed. For *Ur-11*, 30 F_1 plants were grown, and ~ 2000 F2 seeds are available. That F2 population will be challenged with the appropriate bean rust race to score for the *Ur-11* resistance specificity. That data will be coupled with a molecular screening for the 5 indel markers discovered this year to be closely associated with *Ur-11*. These markers were discovered by scoring the MDP and looking for markers with only a few mismatches. Two indel markers located with 160 kb of each other cosegregate with the *Ur-11* locus.

Importantly, we have now placed two very important resistance specificities in very close proximity of each other. The *Ur-3* locus maps to the 11C cluster of CNL (coiled-coil NBS-LRR) genes on Pv11, while the *Ur-11* locus maps to the 11E cluster. With further mapping of this locus, using the same approach described here, other resistance specificities can be fine-mapped and very functional markers with a high-degree of reliability can be developed. The *Ur-3* and *Ur-11* rust resistance genes markers described here have already been used by Dr. Phil Miklas and Dr. Tim Porch in their breeding programs to screen advanced breeding lines. These markers are easier to assay and more diagnostic than the previous RAPD based markers, and are expected to have worldwide utility for detection of the genes across market classes and breeding programs.

V. Research Capacity Strengthening

A Central America / Caribbean (CA/C) bean research workshop supported by the Legume Innovation Laboratory project S01.A4 was held in Tegucigalpa, Honduras from 25-27 July 2017. Leaders of bean research programs from Panama, Costa Rica, El Salvador, Honduras, Guatemala, Mexico, Haiti, Dominican Republic and Puerto Rico participated in the workshop. Each research leader made two presentations. The first presentation described bean research achievements in their country during the past 10 years. The presentations provided several examples where the Legume Innovation Laboratory has made contributions in the development, testing and release of improved cultivars in the region. A keystone to collaboration has been the distribution of regional yield trials and other cooperative nurseries more focused on specific abiotic and biotic constraints. The second round of presentations made by the investigators described research and training needs for the next 10 years to promote the production and consumption of beans. During group discussions, the participants identified areas of research that would benefit from continued collaboration in the CA/C region. The presentations of the workshop were posted on the USDA-ARS FtF Legume Project web site (FtF USDA-ARS Bean Research Team).

Funding was leveraged from the USDA-PASA program in Haiti to support the purchase and transportation of seed of the improved black bean cultivar Sankara from Idaho to Haiti. The National Seed Service (NSS) in Haiti distributed seed to producers for multiplication in irrigated fields during the winter months. During a visit to Haiti in February 2017, Dr. Porch and Dr. Beaver observed that most of the production fields had excellent emergence, vigorous plant development and little or no disease. Although the NSS had contracts to re-purchase the seed for distribution to farmers for production on the hillsides during the summer months, several of these agreements were not honored and the seed was sold in the market. This effort, nevertheless, demonstrated that bean seed produced in the Western U.S. could play a role in supplying countries in CA/C with a dependable supply of disease free, genetically pure basic seed stocks.

VI. Human Resource and Institution Capacity Strengthening

5. **Degree Training in the US or elsewhere**

Name of trainee	Héctor Martínez	Iveth Rodríguez	Diego Rodríguez	Didier Joseph	Carlos Maldonado	Lucy Lund
Country of citizenship	Guatemala	Honduras	Ecuador	Haiti	Guatemala	U.S.
Gender	M	F	M	M	M	F
H.C. institution	ICTA	Zamorano	INIAP	NSS	ICTA	None
Training institution	UPR	UPR	UPR	UPR	NDSU	NDSU
Supervising CRSP PI	J.S. Beaver	T.G. Porch	C. Estevez	J.S. Beaver	Juan Osorno	Phil McClean
Degree program	M.S.	M.S.	M.S.	M.S.	M.S.	M.S.
Field or discipline	Plant breeding	Plant breeding	Plant breeding	Plant Pathology	Plant breeding	Plant genomics
Research project title	Web blight resistance	Drought & heat tolerance	ALS resistance	Haitian bean seed quality	Resistance to anthracnose	Mol. genetics res. to bruchids
Start date	Aug. 2015	Aug. 2015	Aug. 2015	Jan. 2016	Aug. 2015	July 2015
Completion date	Jul. 2017	Sept. 2017	Jul. 2017	May 2018	Dec. 2017	June 2017
Participant trainee and registered on TraiNet?	Yes	Yes	No	No	Yes	No
Training status (Active, Completed, Pending, Discontinued, or Delayed)	Completed	Completed	Completed	Pending		

Name of trainee	Priscila Campos	Jorge Chanaluisa	Klever Arroba	Segundo Gavilanes	Belky Cabana
Country of citizenship	El Salvador	Ecuador	Ecuador	Ecuador	Peru
Gender	F	M	M	M	M
H.C. institution	None	None	None	None	None
Training institution	Zamorano	Zamorano	Zamorano	Zamorano	Zamorano
Supervising LIL PI	J.C. Rosas	J.C. Rosas	J.C. Rosas	J.C. Rosas	J.C. Rosas
Degree program	B.S.	B.S.	B.S.	B.S.	B.S.
Field or discipline	Agronomy	Agronomy	Agronomy	Agronomy	Agronomy
Research project title	Web blight resistance	Web blight resistance	BGYMV resistance	BGYMV resistance	Low fertility
Start date	Jan 2017	Jan 2017	Jan 2017	Jan 2017	Jan 2017
Completion date	Nov 2017	Nov 2017	Nov 2017	Nov 2017	Nov 2017
Participant trainee and registered on TraiNet?	No	No	No	No	No
Training status (Active, Completed, Pending, Discontinued, or Delayed)	To be completed	To be completed	To be completed	To be completed	To be completed

Name of trainee	Enrique Zevallos	Elisa Solis	Maria Besilla	Katya Rivera	Andres Rosas
Country of citizenship	Peru	Guatemala	Ecuador	Honduras	Ecuador
Gender	M	F	F	F	M
H.C. institution	None	None	None	None	None
Training institution	Zamorano	Zamorano	Zamorano	Zamorano	Zamorano
Supervising LIL PI	J.C. Rosas	J.C. Rosas	J.C. Rosas	J.C. Rosas	J.C. Rosas
Degree program	B.S.	B.S.	B.S.	B.S.	B.S.
Field or discipline	Agronomy	Agronomy	Agronomy	Agronomy	Agronomy
Research project title	Low fertility	Low fertility	Low fertility	Heat tolerance	BNF
Start date	Jan 2017	Jan 2017	Jan 2017	Jan 2017	Jan 2017
Completion date	Nov 2017	Nov 2017	Nov 2017	Nov 2017	Nov 2017
Participant trainee and registered on TraiNet?	No	No	No	No	No
Training status (Active, Completed, Pending, Discontinued, or Delayed)	To be completed	To be completed	To be completed	To be completed	To be completed

VII. Achievement of Gender Equity Goals

The development and dissemination of improved bean cultivars using conventional techniques and marker-assisted selection should produce greater or more reliable bean yields. This should contribute to economic growth and improve the lives of the families of bean producers in Central America and Haiti. Co-PIs from Puerto Rico and Guatemala are women. Project S01.A4 also supports the participation of women in formal and informal training activities.

VIII. Implementation of Data Management Plan

A data management plan was prepared and submitted to the Management Office of the Legume Innovation Laboratory. A portion of the data collected by project personnel concerning the Andean and Middle American Diversity Panels, and the SNP data from the ADP, is available on the web site of the USDA-ARS FtF project (www.arsftfbean.uprm.edu). Other data sets will be uploaded into the USAID DDL.

IX. Scholarly Accomplishments

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Poster presented at the Grain Legume Research Conference, Burkina Faso, 13-18 August 2017.

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X. Achievement of Impact Pathway Action Plan

- Many of the bean improved cultivars used in Central America and Haiti were developed with support from the Legume Innovation Laboratory.
- Zamorano continues to be an important source of genetic and foundation seed for the national research institutions, national seed systems in CA/C, NGOs and farmer organizations in Honduras.
- Zamorano also provided foundation seed to the dissemination project coordinated by MSU in collaboration with Technoserve and DICTA in Honduras.
- Supplemental funding provided by the Legume Innovation Laboratory enhanced the capability of the NSS to produce and store bean seed at the research station in Savane Zombi.
- It is encouraging that the bean research programs in Guatemala and Haiti have begun to develop bean breeding populations. This reflects an enhanced capacity to conduct independent research. Within the CA/C region, it is reassuring that bean research in the Dominican Republic and Costa Rica has continued after support from USAID discontinued several years ago. It should be noted, however, that the modest level of funding provided by S01.A4 to support collaboration and training among CA/C bean programs has allowed a regional network to continue to exist.

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes

Report on the Achievement of "Milestones of Progress"

(For the Period: October 1, 2016 – March 31, 2017)

This form should be completed by the U.S. Lead PI and submitted to the MO by April 1, 2017

Project Title: Development and implementation of robust molecular markers and genetic improvement of common and tepary beans to increase grain legume production in Central America and Haiti.

	Abbreviated name of institutions																				
	UPR			USDA-ARS-TARS			Zamorano			NSS-Haiti			ICTA			NDSU			USDA-ARS-Prosser		
	Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved	
Milestones by Objectives	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*
	(Tick mark the Yes or No column for identified milestones by institution)																				
Objective 1																					
1.1 Develop and test on research stations and farms bean breeding lines that combine disease and pest resistance with greater tolerance to abiotic stress.	X	X		X	X		X	X		X	X		X	X					X	X	
1.2 Multiply and maintain breeder and foundation seed stocks of recently-released bean cultivars	X	X					X	X		X	X		X	X							
1.3 Regional testing of small red and black bean breeding lines in the lowlands of Central America and Haiti.	X	X					X	X		X	X		X	X							
1.4 Utilize recurrent selection to develop bean populations for better adaptation to low N soils and greater resistance to web blight.	X	X					X	X											X	X	
1.5 Evaluate pathogen variability and resistance to angular leaf spot, powdery mildew, ashy stem blight, and web blight.	X	X		X	X		X	X		X	X		X	X							
1.6 Support the development of bean breeding populations in Guatemala and Haiti with the goal of releasing a locally-produced cultivar by the end of the five-year extension period.	X	X								X	X		X	X							
1.7 Test the performance of bruchid resistant lines when exposed to natural infestation	X	X					X	X													
Objective 2: Genetic improvement of tepary beans for Central America and Haiti.																					
2.1 Breeding and introgression of BGYMV res., I and bc3 into tepary/common bean hybrids.				X	X																
2.2 Determine potential use of P. vulgaris Indels for tepary genetic analysis and mapping.				X	X																
2.3 Characterize the CIAT tepary bean germplasm collection for BCMV and CBB resistancelines to specific potential growing areas.				X	X		X	X		X	X		X	X							
2.4																					
2.5																					
Objective 3: Develop and implement robust molecular markers for disease resistance genes																					
3.1 Populations will be evaluated for subsequent identification of improved markers for BGYMV, BCMNV, BCMV and rust.	X	X					X	X											X	X	
3.2 Investigate efficacy of available markers for bruchid resistance genes (Arc2, Arl3, PHA and aAI3).				X	X											X	X				
3.3 Establish background information for marker development disease resistance through conducting association mapping analysis.				X	X											X	X		X	X	
3.4																					
3.5																					
Objective 4: Institutional capacity building																					
4.1 In-service training will be provided at NDSU for two Legume Innovation Laboratory scientists to review recent advances in sequencing the bean genome and the utilization of SNP arrays to develop indel markers for traits of economic importance.																X	X				
4.2 Undergraduate students at Zamorano will be provided opportunities to participate in bean research activities related to Legume Innovation Lab project objectives.							X	X													
4.3 M.S. degree training at the UPR of three bean researchers from Central America or the Caribbean	X	X																			
4.4 M.S. degree training at NDSU of two bean researchers from Central America or the Caribbean																X	X				
Name of the PI reporting on milestones by institution	James S. Beaver			Timothy G. Porch			Juan Carlos Rosas			Emmanuel Prophete			Julio Cesar Villatoro			Phil McClean			Phil Miklas		

Name of the U.S. Lead PI submitting this report to the MO: James S. Beaver

Signature ______________________ **Date** ____________

* *Please provide an explanation for not achieving the milestones on a separate sheet.*

VII. Genetic Improvement of Cowpea to Overcome Biotic Stress and Drought Constraints to Grain Productivity (SO1.A5)

Lead U.S. Principal Investigator and University:
Philip A. Roberts, University of California, Riverside, CA 92521

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Timothy J. Close & Bao-Lam Huynh, University of California, Riverside, CA, USA
Benoit Joseph Batieno & Issa Drabo, Institut de l'Environment et des Recherches Agricole (INERA), Koudougou and Kamboinse, Burkina Faso
Francis Kusi & Ibrahim Atokple, Savanna Agricultural Research Institute (SARI), Tamale, Ghana
Ndiaga Cisse, Centre National Recherches Agronomie, Bambey, Institut Senegalais de Recherches Agricole (ISRA) & CERAAS, Thies, Senegal

I. Abstract of Research and Capacity Strengthening Achievements

Multi-location screening of a cowpea aphid resistance panel was completed using uniform test protocols to characterize resistance to aphids and to identify cowpea aphid biotypes in four African and one US locations. Differences between US and African aphid populations were found based on response to resistance source and mitochondrial molecular sequence, and three independent resistance QTL were discovered. Cowpea populations segregating for resistance to pod bugs, flower thrips and aphids were advanced, phenotyped and genotyped for QTL discovery for use in marker-assisted breeding across project countries. Breeder and Foundation Seed were multiplied and distributed to farmers' organizations for Certified Seed production of five recently released large white-seeded varieties in Senegal and four pre-release LIL advanced lines in Burkina Faso. In California, advanced lygus, aphid and disease resistant blackeye lines were tested on-farm and on-station. Seventeen African students including six women engaged in PhD and MS/MPhil degree training programs. Capacity strengthening awards to INERA-Burkina Faso, ISRA-Senegal and SARI-Ghana supported modern seed quality testing and insect culturing and screening development. Continuous short-term training occurred with each Host Country through iterative data analysis and interpretation cycles, and training visits to UC Riverside and Burkina Faso.

II. Project Problem Statement and Justification

The project focus is to 1) discover insect tolerance and resistance QTL for cowpea breeding; 2) increase African and US cowpea productivity by improved varieties with resistance to insect stresses, drought tolerance or disease resistance; 3) expand farmer marketing opportunities with improved cowpea varieties; and 4) provide training and capacity building in modern cowpea breeding. The project is aligned with FTF research strategic priorities 1) crop resistance to heat, drought, salinity and flood; 2) West African Sudano-Sahelian systems emphasizing insect-resistant cowpea; and 3) grain legume productivity. Strategically, our partner countries Ghana, Senegal and Burkina Faso represent primary agro-ecologies for cowpea production in the Sudano-Sahel.

The project uses genomics and modern breeding to improve cowpea yield by targeting insect tolerance and resistance. By leveraging genomic resources developed with CGIAR Generation Challenge Program and USAID Climate Resilient Cowpea Innovation Lab funding, we apply comprehensive modern breeding tools. Insect pests constrain cowpea productivity in West Africa; the project targets insects attacking early (aphids), mid-flowering and pod-set (flower thrips), and later pod-filling (pod-sucking bugs) cowpea stages. Discovery work through phenotyping, genetic mapping and QTL identification needs to be done for these insect pests, using high throughput SNP genotyping, genetic maps, and QTL discovery. The project breeding programs have segregating populations with target traits, providing valuable trait discovery and breeding resources.

Low productivity of agriculture is central to rural and urban poverty in Africa. On-farm cowpea yields in West Africa average 240 kg/ha, even though potential yields are often five to ten times greater. Most of the loss in yield potential is due to drought, poor soil fertility, and insect pests. By targeting insect tolerance and combining with drought tolerance, cowpea productivity, food security and rural incomes can be increased. To increase marketing options, new cowpea varieties must have features desired by consumers - grain appearance, cooking and processing characteristics. Regionally adapted cowpea varieties with large white grain and large rough brown grain resistant to pests would increase marketing opportunities of cowpea farmers and traders in both West Africa and the US.

III. Technical Research Progress

Objective 1. Discover QTL for insect resistance and apply in molecular breeding for target regions in West Africa and the US.

1.1 Aphid resistance: We have tested the genetic relatedness of five sources of cowpea aphid (*Aphis craccivora*) resistance. Field observations in Africa and California indicate differential effects of resistance sources on aphid populations from different cowpea production areas. Cowpea lines IT97K-556-6, KvX295-2-124-99, an IITA wild donor line (TVNu1158), UCR01-11-52/SARC1-57-2, and 58-77 representing a set of resistance donor genotypes plus known susceptible control lines were seed-multiplied in 2014 and 2015 and the seed shared among partners. Uniform screens in locations across all project NARS (Burkina, Ghana, Senegal) and California were conducted in 2014 - 2017 in field plots or screenhouses, with 4-fold replication, using standard resistance assessment scales across for all tests. The uniform test design and coordination planning for the aphid resistance assessment was developed by the project team. At least two years of date were collected per project country. Tests failed in some locations/years due to lack of aphid infestation. For example, in Senegal in 2017 no aphids appeared, so no evaluation was possible in the field or screenhouse. A summary of the multi-location screening results is presented in Table 1. The resistance donors and susceptible controls were SNP genotyped in FY14, coordinated by UCR. The same panel was screened again in 2017 by INERA in Burkina Faso using aphids collected at Kamboinsé and Pobé-Mengao, to look for differential lines for aphid resistance between the two aphid colonies. The results are being prepared for publication.

Genetic mapping of the aphid resistance in IT97K-556-6 at UCR had revealed two QTLs on cowpea linkage groups LG1 and LG7, published in 2015 (Huynh et al., 2015). The aphid resistance found by SARI in the Ghana line SARC-1-57-2 was analyzed genetically as part of a recurrent backcrossing program. Inheritance indicated a single dominant gene governing resistance. Using SSR marker analysis for the SARC-1-57-2 resistance together with genomewide SNP markers, as part of Richard Agyare's SARI – UCR training in 2016, we were able to map the major resistance locus from this donor to cowpea LG 10, using two SNP-genotyped biparental RIL populations. This finding also confirmed that the SARC-157-2 aphid resistance is distinct from that in the IT97K556-6 line, which is controlled by gene on LG7 and LG1. This work submitted to *Plant Breeding* in 2017 is under review.

A follow-up study was initiated upon confirmation that SARI's source of resistance (SARC 1-57-2) was distinct from that in IT97K 556-6. The LIL project in Ghana collaborated with The Kirkhouse Trust project in pyramiding the two gene sources into farmer-preferred cowpea varieties in Ghana. Under this collaboration, Kirkhouse Trust fully sponsored a 4-year PhD study of a young scientist (Patrick Attamah) to work on the gene pyramiding. The two aphid resistance QTLs found in IT97K 556-6 will be deployed in marker-assisted backcrossing. The student will also convert SNP markers to PCR-based markers and deploy them in marker-assisted selection at SARI. Screening populations are being developed for both phenotyping and genotyping both in Ghana and at UCR. Conversion of SNP markers and a search for SSR markers that can also be used to select for the two sources of resistance are underway. Leaf samples will soon be sent to UCR for genotyping.

The IT97K-556-6 source of aphid resistance was used to introgress the two resistance QTLs into two main US blackeye varieties, CB46 and CB50 by recurrent backcrossing. Linkage of resistance to pink eye-color was broken and the advanced lines positive for QTL SNP marker alleles (BC5F2) were greenhouse aphid-screened to confirm resistance, and grown in 2016 at the UC Kearney Research Center (KREC) for yield and grain quality evaluation (Table 2). The 3 CB46 aphid resistant lines (designated 2014-008-x) and CB50 aphid resistant lines (designated 2014-010-x), performed equivalent to the recurrent parent cultivars without aphid pressure (Table 2). The two best performing lines with CB46 and CB50 background were multiplied in the greenhouse and field performance tested in main season 2017. Growth and pod load data looked very promising, and harvested grain is currently being cleaned for yield and grain size data collection.

We are working with Dr. B. Pittendrigh and M. Tamo (Project SO1.B1) in the characterization (molecular fingerprinting) of the aphid isolates representing the different aphid populations at each location. This will be especially valuable if, as expected, aphid biotypes are delineated on the cowpea resistance sources. Samples of aphids were collected and stored for DNA extraction and genotyping. For example, in Burkina Faso, aphids were collected from Kamboinsé, Pobé-Mengao and Farako-Ba representing three diverse cowpea production zones. Five samples were also collected in different fields in the Bambey, Senegal area in 2016, although in the 2017 rainy season, no aphid population appeared so samples were not obtained. Aphid samples from SARI, Tamale, Ghana and UCR, Parlier, Fresno Co. California were used to compare old-world and new world *Aphis craccivora* by complete sequencing of their mitochondrial genomes (mitogenomes). The comparison showed only very minor differences between the sequences (99.7% identity), reflecting only very recent divergence of the old and new world forms. A joint paper for this work was published in *Agrigene* in 2017. From the wild donor IITA line TVNu1158 a RIL population has been developed for mapping QTL and it was genotyped using the 60K SNP iSelect by UCR. This work was conducted in collaboration with Drs. Fatokun and Boukar at IITA, Nigeria.

1.2 Flower thrips resistance: We identified and SNP-mapped loci (*Cft-1* and *Cft-2*) for flower thrips (*Megalurothrips sjostedti*) tolerance donated by Sanzi in the cross Sanzi x Vita 7, and these loci are promising for introduction and selection in breeding progenies but require better definition through phenotyping. Additional sources of thrips tolerance are 58-77 and Tvx3236. In Senegal, during the 2016 and 2017 rainy seasons, the RIL populations Sanzi x Vita 7; 58-77 x Yacine and the cowpea MAGIC population were planted each in two trials with flower Thrips control and no spray comparison plots. Data were obtained on number of peduncles and pods and number of Thrips in five flowers for the first population. Thrips damage rating was also obtained for both populations. The families derived from crosses of resistant (Sanzi x 58-77) and large seeded varieties (ISRA-3178 and ISRA-3217) were advanced to the F4 and F5 during the off-season and rainy season. The M4 and M5 generation of selected Yacine lines was also evaluated and additional selections made. Promising results were obtained for the second time after 8 months of Yacine and Melakh M4 lines tests for reaction to bruchids. The resulting lines were bulked for seed multiplication and large scale evaluation for bruchid resistance.

The Sanzi x Vita 7 and Yacine x 58-77 RIL populations from Senegal were phenotyped for the third time for flower Thrips tolerance, both at the Manga station in the Sudan Savanna zone and at Nyankpala in the Guinea Savanna zone. Harvesting is in progress and data will be analyzed together with the data from the two previous seasons. This will help check for lines that show consistency in supporting low numbers of flower Thrips. We are planning to co-analyze the Senegal and Ghana phenotype data to definitively map the flower Thrip resistance determinants.

In Burkina Faso, 20 cowpea genotypes (TVx3236, Sanzi, NS-1, NS Farako-Ba, Pobe local, Donsin local, Moussa local, Nafi, Tiligré, Gourgou, Komcalle, KVx165-14-1, KN-1, KVx780-1, KVx 780-3, KVx404-8-1, TVu1509, KVx745-11P, KVx780-6, KVx61-1) were screened for flower Thrips tolerance. The screening confirmed resistance in genotypes Sanzi, TVx3236 and TVu1509. For lines released in 2012, the screening confirmed resistance for Nafi. In the lines in the release pipeline, the new line included this year, KVx780-3, was the most tolerant, followed by KVx780-1, but KVx780-6 showed some susceptibility compared to 2016. Also, KVx165-14-1 confirmed its tolerance levels to flower Thrips. Crosses were made using KN-1/Sanzi, KN1/TVx3236, Komcalle/Sanzi, Komcalle/TVx3236, KVx780-3/Sanzi, KVx780-1/ Sanzi, and Tiligre/Sanzi. These populations will be genotyped and phenotyped for genetic analysis and marker discovery.

1.3 Pod-sucking bug resistance: The Heteropteran Coreid pod-sucking bugs (*Clavigralla tomentosicollis* complex) are a major yield suppressor in Burkina Faso, Ghana and neighboring countries. To identify genes or QTL for resistance to pod-sucking bugs we used biparental resistant x susceptible segregating populations in Burkina Faso in FY14 and FY15 to map QTL and initiate their selection as a new breeding target. The primary resistance donor is IT86D-716. Problems with germination in these populations resulted in insufficient data sets for mapping. Two existing F2 populations generated from resistance donor IT86D-716 with parents Kvx771-10G (Nafi), Tiligre, Gourgou, and IT98K-205-8 enable combining Striga resistance with pod-sucking bug tolerance. The parents were genotyped through LGC Genomics and the F2 and F3 populations are being phenotyped for pod bug resistance in Burkina Faso, in collaboration with Dr. Dabire (Figure 1). A second set of segregating materials was developed from crosses between six parents involving the resistant IT86D-716 to provide more viable populations.

The two segregating materials were screened under artificial infestation at Kamboinsé research station for genetic analysis. Results showed that resistance might be under multi-genic additive gene control (Table 3). Leaf samples of F1, F2, and BC1F1 were collected and sent to UCR for genotyping. A local bench genotyping was also done at Kamboinsé using 47 SSR markers to look for markers associated with resistance (Figure 2). Figure 2 shows the results with four markers which amplified the DNA of the resistant and susceptible parents. However, only markers MA127 and MA84 were polymorphic. Amplification with marker MA127 yielded two bands (200pb and 175pb) in the resistant parent and a single 200bp band in the susceptible parent. With marker MA84, the resistant and susceptible parent each has one band at 250bp and 225bp, respectively. Markers MA114 and MA80 were monomorphic, generating bands of the same molecular weight in both parents. Figure 3 shows the typical damage caused by pod-sucking bugs on cowpea. Leaf material from the new sets at F7 has been collected for SNP genotyping and QTL mapping resistance to pod bugs, Striga, aphids, and bruchids contained in the same population set. New crosses were made using only a single plant for maintaining purity of crosses. Leaf samples of parents and F1 in these crosses were collected and dried for sending to UCR for genotyping and progenies will be phenotyped in Burkina Faso.

Insect characterization: For the three insect groups (aphids, thrips, pod bugs), we collaborated with Dr. Pittendrigh and Dr. Tamo (Project SO1.B1) to utilize our project trial sites to collect insect samples for use in molecular characterization of the insect populations. Collections are being made at all test locations, thereby allowing a robust comparative profiling of insect populations. We have tested a protocol for insect DNA collection, in which insects are placed in plastic bags with silica gel packs; this dries the insect samples and preserves the DNA. As described above under Objective 1.1, aphid samples from SARI, Tamale, Ghana and UCR, Parlier, Fresno Co. California were used to compare old-world and new world *Aphis craccivora* by complete sequencing of their mitochondrial genomes (mitogenomes). The comparison showed only very minor differences between the sequences (99.7% identity), reflecting only very recent divergence of the old and new world forms. In Burkina Faso, pod bugs were collected from Kamboinse, Pobe-Mengao and Farako-Ba. In Senegal samples were obtained for cowpea aphids in the Bambey production area.

The LIL project in Ghana also evaluated the MAGIC population for insect pest resistance both in an insectary and in the field. The insectary screening for aphid resistance using the seedling screening technique identified M031 and M262 as aphid resistant lines. The field evaluation covered all the major pests at the various growth stages of cowpea -

vegetative, flowering and podding. Data on the field evaluation are being compiled for analysis. The evaluation will be extended to screening for sources of resistance to cowpea weevil *Callosobrucus maculatus*.

Objective 2. Complete release and validation of advanced cowpea lines developed under the Pulse CRSP in Burkina Faso, Senegal, and US.

2.1. We continued to use our genotyping capability to advance the BT gene introgression for Maruca resistance with our SNP marker panel. Genotyping was initiated in FY14 primarily focused on background selection with genome-wide markers in segregating progeny of backcross breeding populations in Burkina Faso and Ghana. The goal is to expedite the selection of lines with the highest percentage of elite recurrent parent content in each country (e.g., improvement of elite variety IT97K-499-35 in Ghana and several elite local varieties in Burkina Faso, including Moussa Local, Gourgou 3, 7 and 11, IT98K-205-8 and KVX 745-11P). In Burkina Faso BC3 were genotyped in FY14. Populations were advanced to the BC3F5 and BC5F3 stages and leaf samples were collected and some were SNP genotyped. Farmers' managed trials in CFTs are ongoing in 2017 at three locations for agronomic performance and also a single-site trial was conducted under insect net protection for resistance efficacy of the introgressed lines. In 2017, HC partners received training on Tassel for GWAS analysis at UCR in January. Zida Serge Felicien spent the month of January at UCR to learn more about genetic resources handling and genotypic data analysis.

2.2. We are capitalizing on the previous Pulse CRSP breeding effort by completing the release requirements of several advanced breeding lines that are in the final stages of performance testing in Burkina Faso, Senegal and California.

In Senegal, a new version of Melakh resistant to Striga was obtained through marker-assisted selection. The selected BC4 F3 families were multiplied during the rainy season in 2016. These Striga resistant lines were evaluated at 3 sites in 2 farmers' fields at each site in 2017. Also the line ISRA-3006 was seed-multiplied; this line was obtained from a cross between the local variety Baye Ngagne and the Mougne-derived line ISRA-514 which was resistant to aphids in earlier tests, both with the same seed type. This line was yield-tested earlier and had good performance with larger grain size and same color. Dr. Cisse decided to promote it as a variety because it is earlier maturing than the local variety. On-farm demonstration trials were conducted at 3 farmers' fields near the Bambey station in 2017. The cowpea MAGIC population was multiplied during the off-season and introduced in a preliminary yield trial at the ISRA/CNRA Bambey station during the 2016 rainy season. Data were obtained on time to flowering, maturity, numbers of peduncles and pods, 100-grain weight and yield. The same trial was conducted again in 2017. In the 2017 rainy season, 1700 new cowpea lines were introduced in preliminary yield trials at Bambey. These were tested in 17 designs with 2 replications, each having 100 lines. These lines were obtained from elite crosses between Melakh, Yacine and the newly released 5 varieties (Table 4). They were selected for grain quality (size and color). These 5 varieties released in 2015 (Lisard, Thieye, Leona, Kelle and Sam) were again multiplied on 0.25 ha each in 2016 and 2017 for additional Foundation Seed production at the Bambey station. Amounts of Breeder's Seeds of new and current cowpea varieties produced in Senegal in 2017 are given in Table 5. RESOPP received Breeder Seed obtained during the off-season to multiply on 1 ha each for Foundation Seed production during the rainy season. The new version of Striga resistant Melakh and ISRA-3006 were multiplied for Breeder Seed on about 0.01 ha.

In Burkina Faso, 20 pre-release CRSP advanced lines developed by the breeding team were on-farm performance tested in 2013, and the best nine lines were re-evaluated in 2014. Multi-location tests were conducted at Saria, Pobe, and Kamboinse in Burkina Faso during the 2015 main rainy season. The four best performing of the nine lines plus two standard checks were used for testing and these were re-evaluated in the off-season in 2016 and 2017, emphasizing yield and grain quality, plus any disease susceptibility. Trial design was based on using 4-row plots, 5 m long and 4 reps arranged in a RCBD. Breeder Seed of the best lines chosen for release submission was produced at Saria during the main season 2016. About 20 kg of Breeder Seed of each of these lines was used to initiate Foundation Seed production in the 2017 off-season. During the LIL meeting held in Ouagadougou, a visit was made to the cowpea group supported by INERA through LIL, ILCRC, and TLIII funds at Gourcy (Zindiguesse and Lago) to produce Certified Seed covering 10 ha in Zindiguesse and 5 ha in Lago. INERA is completing forms to be submitted to the National Variety Release Committee for evaluation in 2018. If approved, the varieties will be released by the end of 2018.

In California, advanced breeding lines were field tested for release potential, based on performance data collected in previous on-station trials. These represent CRSP developed lines that carry a combination of lygus bug tolerance, and root-knot nematode and Fusarium wilt resistance. For the best advanced blackeyes from 2015, we conducted on-farm yield trials in 4 Tulare Co. farmers' fields (Table 2) and on-station trials at the UC Kearney Station, Fresno Co. (Tables 6 and 7), in main season 2016 (harvested in October-November 2016) to assess commercial yield performance. Seed size and yield data from the trials are presented in Tables 2, 6 and 7, together with field assays conducted for resistance to three common root-knot nematode species and a greenhouse assay for resistance to Race 4 of Fusarium wilt. The 10 lines plus the standard varieties CB46 and CB50 were tested under insect-protected conditions (Table 2), while a no-insecticide unprotected lygus screening trial was conducted with two lines with lygus bug tolerance (Table 7). The test design was a four-row 4-fold replicated RCBD for the trials with the center two rows machine harvested. Yield weights, 100-seed weights and lygus damage to seed were assayed. All yield and performance data were analyzed by standard ANOVA.

Trials comparing yield and grain quality of nine new blackeye breeding lines together with CB46Rk^2, CB46, and CB50 were conducted under early-planted, double-flush production conditions at the Kearney Station (Table 2). Two most promising lines were evaluated together with CB46Rk^2 and CB46 in large strip plots in four Tulare County commercial blackeye fields. Overall the yields were higher than in 2015. Some advanced lines including four BC5F2 lines with two aphid-resistance QTLs backcrossed into CB46 and CB50, had equivalent grain yield to CB46 at KREC, and one line had equivalent or higher yield compared to CB46 at the Tulare Co. locations (Table 2). Some lines also combine the advantage of stronger, broad-based resistance to root-knot nematodes and resistance to Fusarium wilt Race 4 (Table 2). They have seed size that is consistently the same or larger than CB46 but less than CB50. CB46Rk^2, a new version of CB46 with improved resistance to root-knot nematodes but with slightly smaller seed size, performed similarly to CB46 in the Tulare strip trials and at KREC in 2016 (Tables 2, 6).

In 2016 three lines first selected in 2007-2009 were evaluated under insect unprotected conditions at Kearney. These lines resulted from a long-term breeding effort to combine lygus resistance with high quality grain and high production. Selection and testing over this period resulted in choosing a best line, 07KN-74, for larger scale testing in 2016. Lygus pressure was heavy in 2016, resulting in grain yield loss of 36% in the check CB46 in comparison with the protected conditions in the same field. The unprotected yields were significantly higher than CB46 for the advanced line 07KN-74, further confirming strong yield ability under lygus pressure. This early maturing blackeye may be suitable as an option for growers desiring shorter season single-flush production.

Three trials were planted in May 2017 in Tulare Co. with four lines (CB46, N2, 10K-29, CB46Rk2) in large 0.5 acre field-length 6-row strips (harvested October 2017) in three farmer field sites. Trials at the UC Kearney station were planted in June 2017 with nine lines (CB46, CB46Rk2, two new lygus resistant lines and two N lines) in four-extended row 4-fold replicated RCBD. Harvesting, threshing and seed cleaning is underway at time of reporting.

During the 2017 main rainy season in Burkina Faso new varieties were multiplied as Breeder Seed on 1.5 ha for additional Foundation Seed production. The resulting products will be provided to Certified Seed producers including new farmer organizations for increase and demonstration in 2018.

Objective 3. Increase capacity of NARS in Burkina Faso, Ghana and Senegal to serve the cowpea sector.

Short-term Training: Short-term training in molecular breeding for young trainee breeders and NARS scientists was continued in FY17. Continuous short-term training occurred through iterative data analysis and interpretation cycles using the phenotyping and genotyping data generated by each of the three Host Country partner teams (about 12 participants). To continue periodic intensive training, we conducted face-to face training and planning with HC partners at UCR in January 2017 and in Ougadougou, Burkina Faso in August 2017. The molecular breeding approach is complex and requires a combination of hands-on experience with self-generated data sets, augmented with periodic intensive training workshops to improve knowledge, skills and problem-solving. The technologies underlying the genotyping capability are in a state of frequent enhancement and upgrade, requiring periodic training input. Thus both young breeder trainees new to the programs and experienced breeders from the HC NARS are in need of this training.

Zida Serge Felicien from INERA received a one-month training in January 2017 on GWAS and molecular data handling at UCR. Also in Burkina Faso, more than 1000 farmers received training through direct engagement in field practicals, field days or theoretical training for good production practices. This included more 700 women farmers from 5 different associations (YiYE, Gourcy, Sanguié, Pobé-Mengao, and Dedougou).

Degree Training: We conducted degree training for two graduate students in the report period at UCR and 15 in Africa (2 in Senegal, 6 in Ghana and 7 in Burkina Faso). The trainees are described in detail under Section VI 2. In Ghana, the LIL project collaborated with Innovation Lab for Climate Resilient Cowpea and the Kirkhouse Trust to engage graduate students co-supervised on topics developed from the LIL project at SARI. Zida Serge Felicien and SIDIBE Hamadou, two of the Burkina team members, registered at the University of Ouagadougou for a Ph.D. are partially supported. Zida will be using the UCR platform for genotyping and short time training and SIDIBE is working on flower Thrips resistance. Coulibaly Soumabere defended his M.Sc. on pod-sucking bug resistance in Burkina Faso. Adelaide Ouedraogo, a student registered in the WACCI program is working on aphid resistance using the aphid resistance panel; he is registered at the University of Ouagadougou for a PhD. Alectra and mutagenic cowpea materials were genotyped with the UCR platform -- this genotyping supported two student activities, Dieni Zakara registered at WACCI and Karidiatou Gnakambary at the University of Ouagadougou for PhD.

IV. Major Achievements

Under Objective 1.1 -- Aphid resistance

A differential cowpea panel of aphid resistance sources and control lines was seed-multiplied and used in multi-location field screening and screenhouse seedling screening during FY15-FY17. Using a uniform test protocol for aphid biotype and resistance screening under field and greenhouse conditions, several aphid resistance sources effective against both US and West African aphid populations were identified. This has allowed differentiating biotypes, for example between Senegal and California CB27 has a resistant reaction in Senegal while susceptible in California. Reaction in Senegal and Ghana seems to highlight similar biotypes in the two zones.

Sets of F1 and F2 populations were made from aphid resistant x drought tolerant line crosses at SARI, Ghana.

F1 and F2 populations were made from aphid resistant x Striga resistant farmer-preferred variety crosses by INERA, Burkina Faso. Aphids are being reared to be used in screening for genetic studies under a PhD student project. This student is registered at WACCI. Recent work showed some close resemblance between aphids from Pobé-Mengao and Kamboinse but while awaiting confirmation by molecular characterization, a second round of screening has been undertaken. Agricultural technicians screened the material in Kamboinsé using aphids from Kamboinsé and Pobé-Mengao.

Advanced backcross progenies were developed by adding aphid resistance QTLs into recurrent parents CB46 and CB50 and field tested, to select for California blackeyes with aphid resistance for the US production system.

Three aphid resistance loci were genetically mapped to three different cowpea chromosomes.

The mitochondrial genomes of cowpea aphid populations from Ghana and California were completely sequenced and compared for their relatedness, in cooperation with LIL project SO1.B1.

Under Objective 1.2 – Flower thrips resistance

Segregating populations were developed in Senegal and Ghana from mutagenesis or from hand crosses using three sources of thrips resistance. These are in various stages of phenotyping and genotyping for QTL mapping. Tolerant lines were identified in Burkina Faso and crosses were made in the 2017 off-season. The populations will be used in genetic studies and new lines development. Agricultural technicians screened the material using Thrips from Kamboinsé.

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Under Objective 1.3 – Pod bug resistance

A new segregating population between IT86D-716 and Nafi was developed in Burkina Faso for use in QTL mapping for pod bug resistance, and is under phenotyping and genotyping analysis. F1, F2 and BC1F1 leaf samples were sent to UCR and genotyped and were also phenotyped in Burkina Faso. Genotypic data analysis showed some issues regarding the homozygosity of parents used. Phenotypic analysis showed multi-genic gene action for resistance to these insects.

Under Objective 2.2 – Variety releases

Formal release of five large white-seeded CRSP cowpea varieties in Senegal by ISRA was followed up with additional Breeder and Foundation Seed production of each variety and distribution to Farmers' organizations for Certified Seed development.

An improved version of Melakh with Striga resistance was developed by ISRA, Senegal and multiplied for Breeder Seed, and is currently in demonstration trials in 6 farmers' fields. The line ISRA-3006 with speckled black grain (Mougne type) was also multiplied for Breeder Seed and is in demonstration on-farm locations this season.

Four pre-release CRSP advanced cowpea lines were re- evaluated in multi-location tests at Saria, Pobe, and Kamboinsé during FY15 - FY17, emphasizing yield and grain quality, plus any disease susceptibility. The release petition to the National Variety Release Committee has been re-scheduled for FY19. Breeder Seed of each of these lines was produced and maintained at the INERA Saria Station and used for Foundation Seed production in the FY17 rainy season.

Fifteen African students (5 female, 10 male) have engaged in PhD and Master's degree training programs within the project.

The project was awarded Capacity Strengthening awards from the MSU management entity, which were used to acquire seed quality and viability testing materials for INERA, Burkina Faso, for the development of cowpea seed cold storage capability upgrade with backup generator for ISRA, Senegal, and insect culture and screening facility for SARI, Ghana. These capacity enhancement projects were completed in Summer, 2017 and are now functional and offering optimal conditions for cowpea seed conservation and research (see Section V).

V. Research Capacity Strengthening

Approval through the LIL was granted for $13000 to fund INERA, Burkina Faso breeding activity enhancement at Kamboinsé research station to acquire seed quality and viability testing materials to ensure quality and viable seed are stored or distributed to farmers. The material was acquired and will be used during off-season 2017 to check the long-term storage of germplasm and quality of seed harvested this year.

Approval through the LIL was granted for $17547 to fund the rehabilitation of the screenhouse for ISRA, Senegal at their Bambey station. This upgrade has been made and implemented to benefit the ISRA cowpea research requiring insect resistance screening capability.

SARI was awarded $17,300 for a Host Country Institutional Capacity Strengthening Award to renovate an old entomology lab at Manga station to be used for flower Thrips culturing and screening for resistance. The lab is now functional and the initial work after the renovation involves training of project staff and students studying under the LIL lab project at the Manga Station in flower Thrips culturing and screening for resistance. Among the students were those who received sponsorship from the Association of Africa Universities (AAU) to come to Manga station for internships to learn flower Thrips culturing and resistance screening. The lab will be used to culture Thrips in large numbers to screen all the breeding lines as well as populations in search for promising lines with resistance to flower Thrips.

VI. Human Resource and Institution Capacity Strengthening

6. Short-Term Training

Please see Section III, Objective 3 for a description of the short-term training activities.

7. Degree Training in the US or elsewhere

Trainee 1:
i. Name of trainee: Arsenio Ndeve
ii. Country of Citizenship: Mozambique
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: Eduardo Mondlane University
v. Institution providing training: University of California - Riverside
vi. Supervising LIL PI: Philip A. Roberts & Timothy Close
vii. Degree Program: PhD, Plant Pathology
viii. Field or Discipline: Plant pathology and genetics
ix. Research Project Title: Genomewide selection for disease and drought tolerance in SE African cowpeas
x. Start Date: January 2012
xi. Projected Completion Date: December 2016
xii. Is trainee USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 2:
i. Name of trainee: Sassoum Lo
ii. Country of Citizenship: Senegal
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: ISRA
v. Institution providing training: University of California - Riverside
vi. Supervising LIL PI: Philip A. Roberts & Timothy J. Close
vii. Degree Program: MS initially, now PhD, Plant Genetics
viii. Field or Discipline: Plant breeding and genetics

ix. Research Project Title: MABC for enhanced seed size in cowpea
x. Start Date: March 2014
xi. Projected Completion Date: June 2018 (projected)
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 3:
i. Name of trainee: Binta Sarr
ii. Country of Citizenship: Senegal
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: ISRA
v. Institution providing training: University of Thiès at Bambey
vi. Supervising LIL PI: Ndiaga Cisse
vii. Degree Program: BS
viii. Field or Discipline: Agronomy
ix. Research Project Title (if applicable): Evaluation of Thips resistance in cowpea
x. Start Date: June 2016
xi. Projected Completion Date: Completed in August 2017
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Completed

Trainee 4:
i. Name of trainee: Zida Serge Felicien
ii. Country of Citizenship: Burkina Faso
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Burkina Faso
v. Institution providing training: INERA
vi. Supervising LIL PI: I. Drabo and J. Batieno
vii. Degree Program: Ph.D. University of Ouagadougou
viii. Field or Discipline: Plant breeding
ix. Research Project Title (if applicable)
x. Start Date: 2016 (field research)
xi. Projected Completion Date: Dec. 2019
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 5:
i. Name of trainee (First and Last Name): Emanuele Yaw Owusu
ii. Country of Citizenship: Ghana
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: KNUST, SARI and UCR
vi. Supervising LIL PI: R. Akromah (F. Kusi mentor)
vii. Degree Program: MS Plant Breeding
viii. Field or Discipline: Plant breeding

ix. Research Project Title: Combining early maturity, seed size and thrips resistance traits in cowpea
x. Start Date: 2014
xi. Projected Completion Date: Dec 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Completed

Trainee 6:
i. Name of trainee (First and Last Name): Poda Saadon Leandre
ii. Country of Citizenship: Burkina Faso
iii. Gender: male
iv. Host Country Institution Benefitting from Training: INERA, Burkina Faso
v. Institution providing training: KNUST, SARI and UCR
vi. Supervising LIL PI: R. Akromah and F. Kusi
vii. Degree Program: M.Phil. Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Phenotyping cowpea for *Striga* and flower thrips resistance in Northern Ghana
x. Start Date: 2014
xi. Projected Completion Date: 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Completed

Trainee 7:
i. Name of trainee (First and Last Name): Godfred Agyeman Duah
ii. Country of Citizenship: Ghana
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: UDS, SARI and UCR
vi. Supervising LIL PI: N. Opoku and F. Kusi
vii. Degree Program: M.Phil. Biotechnology
viii. Field or Discipline: Biotechnology
ix. Research Project Title: Genetic relatedness of the cowpea aphid resistance panel
x. Start Date: 2014
xi. Projected Completion Date: 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 8:
i. Name of trainee (First and Last Name): Mohammed Abdul Ganiu
ii. Country of Citizenship: Ghana
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: UDS, SARI and UCR
vi. Supervising LIL PI: B. Badii and F. Kusi
vii. Degree Program: M.Phil. Agronomy

viii. Field or Discipline: Agronomy
ix. Research Project Title: Evaluation of aphid resistance panel to *Aphis craccivora,* Koch (Homoptera: Aphididae) in Ghana
x. Start Date: 2014
xi. Projected Completion Date: 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 9:
i. Name of trainee (First and Last Name): Gloria Tetteh-Kubi
ii. Country of Citizenship: Ghana
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: UCC, SARI and UCR
vi. Supervising LIL PI: M. Botchey, F. Kusi and Aaron Tetteh Asare
vii. Degree Program: Ph.D. Entomology Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Improving Field Resistance of Cowpea Genotypes to Cowpea Aphid
x. Start Date: 2014
xi. Projected Completion Date: 2018
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 10:
i. Name of trainee (First and Last Name): Patrick Attamah
ii. Country of Citizenship: Ghana
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: KNUST, SARI and UCR
vi. Supervising LIL PI: R. Akromah and F. Kusi
vii. Degree Program: M.Phil. Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Screening and genetic analysis of drought tolerance in SARI's favorite cowpea lines
x. Start Date: 2014
xi. Projected Completion Date: 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 11:
lviii. Name of trainee (First and Last Name): Mouhamadou Moussa Diangar
lix. Country of Citizenship: Senegal
lx. Gender: Male
lxi. Host Country Institution Benefitting from Training: ISRA
lxii. Institution providing training: WACCI

lxiii. Supervising LIL PI: N. Cisse
lxiv. Degree Program: Ph.D. Plant Breeding
lxv. Field or Discipline: Plant Breeding
lxvi. Research Project Title (if applicable): Cowpea resistance to Striga
lxvii. Start Date: January 2015
lxviii. Projected Completion Date: August 2019
lxix. Is trainee a USAID Participant Trainee and registered on TraiNet? No
lxx. Training status: Active

Trainee 12:

i. Name of trainee: Coulibaly Soumabere
ii. Country of Citizenship: Burkina Faso
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Burkina Faso
v. Institution providing training: INERA
vi. Supervising LIL PI: I. Drabo and J. Batieno
vii. Degree Program: M.Sc. University of Ouagadougou
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Genetics of pod sucking bug resistance in B. Faso
x. Start Date: March 2016 (field research)
xi. Projected Completion Date: March 2017
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Completed

Trainee 13:

i. Name of trainee: Adelaide Ouedrogo
ii. Country of Citizenship: Burkina Faso
iii. Gender: female
iv. Host Country Institution Benefitting from Training: Burkina Faso
v. Institution providing training: INERA
vi. Supervising LIL PI: I. Dr. J. Batieno
vii. Degree Program: PhD, WACCI
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Aphids' resistance in Cowpea in B. Faso
x. Start Date: November 2017 (field research)
xi. Projected Completion Date: December 2019
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 14:

i. Name of trainee: SIDIBE Hamadou
ii. Country of Citizenship: Burkina Faso
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Burkina Faso
v. Institution providing training: INERA
vi. Supervising LIL PI: Dr. J. Batieno

vii. Degree Program: PhD University of Ouagadougou
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Genetics of Thrips resistance in B. Faso
x. Start Date: November 2017 (field research)
xi. Projected Completion Date: December 2019
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 15:

i. Name of trainee: Gnankambary Karidiatou
ii. Country of Citizenship: Burkina Faso
iii. Gender: female
iv. Host Country Institution Benefitting from Training: Burkina Faso
v. Institution providing training: INERA
vi. Supervising LIL PI: Dr. J. Batieno
vii. Degree Program: PhD University of Ouagadougou
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Mutagenic cowpea for multi-resistance in B. Faso
x. Start Date: November 2016 (field research)
xi. Projected Completion Date: December 2018
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 16: (Kirkhouse Trust/LIL collaborated sponsored PhD)
i. Name of trainee (First and Last Name): Patrick Attamah
ii. Country of Citizenship: Ghana
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: KNUST, SARI, Kirkhouse Trust and UCR
vi. Supervising LIL PI: R. Akromah, A. W. Kena and F. Kusi
vii. Degree Program: PhD Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Pyramiding two sources of aphid resistance genes in farmer preferred varieties in Ghana
x. Start Date: 2017
xi. Projected Completion Date: 2021
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 17:
i. Name of trainee (First and Last Name): Tapsoba Flora Addisa
ii. Country of Citizenship: Burkina Faso
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: KNUST, SARI and UCR
vi. Supervising LIL PI: R. Akromah and F. Kusi

vii. Degree Program: M.Phil. Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Screening multi-parent advanced generation inter-cross (MAGIC) population for resistance to cowpea aphid (*Aphis craccivora*)
x. Start Date: 2015
xi. Projected Completion Date: 2017
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

VII. Achievement of Gender Equity Goals

The project continued to give technical support to women farmer groups who are in the cowpea production systems. During the year under review two hundred farmers, about 70% women, were exposed to new improved cowpea varieties that are resistant to Striga and aphids by SARI, Ghana. They were trained in best agricultural practices suitable for cowpea production using IPM principles to reduce indiscriminate application of chemical insecticides. Also in collaboration with AGRA Inoculant project, ten FBOs in cowpea production from ten districts in the Upper East region of Ghana were educated in integrated management of insect pests of cowpea. The LIL project at SARI collaborated with Maize improvement project, ILCRC, and Kirkhouse Trust to train over 1200 farmers and field officers of MoFA in Fall Army worm control strategies (Figures 4-6), at least 50% women. The outbreak of the pest was found very severe on maize, cowpea and other field crops in Ghana. A factsheet – 'Fall Armyworm [*spodoptera frugiperda* (j. e. smith)] outbreak in Northern Ghana – Facts and management approaches,' was produced to guide farmers in identification and control and to serve as training material for MoFA field officers.

The LIL project also collaborated with ILCRC, Kirkhouse Trust and University of Cape Coast to host 350 farmers during field days and training at Manga station. Farmers were introduced to strategies to manage insect pests of cowpea, such as using extra-early and early maturing varieties both under sole and maize/cowpea intercrop. Other strategies introduced to farmers were scouting for incidence and severity before deciding on the use of insecticide. This was used to guide the farmers against indiscriminate application of insecticide and its associated problems such as human and animal poisoning, pollution of water bodies and the environment. Use of host-plant resistance was also prominent among the strategies presented to farmers. Forty-five final year Agriculture students from Bawku Senior High School also visited Manga Station to learn about insect pests of cowpea, their management practices and how to breed for insect pest resistant cowpea varieties (Figures 7-9).

In Senegal, ISRA continued to work with the farmers' organization RESOPP and the IITA/USAID Cowpea Out-Scaling Project in West Africa (COSP) training of its members on seed production and post-harvest operations. More than 200 women producers were trained in FY17.

In Burkina Faso, 220 women producers were trained on cowpea production and seed storage and about 70 women conducted demonstration tests in FY17. In the Certified

Seed production group of 58 farmers, 39 were women and 19 men, and a group a more than 600 women from YiYE Association of Women were trained. 50 women were trained on cowpea processing and finance management held in March 2017. The project has four female graduate student trainees embedded in the research program.

VIII. Implementation of Data Management Plan

The primary data management plan is submission of the url linkages to data sets published and analyzed in the Open Access publications listed in Section IX. These will be indicated in the USAID DDL, with a completion date for the current datasets of November 30, 2017.

IX. Scholarly Accomplishments

Huynh, B.-L., Ehlers, J.D., Muñoz-Amatriaín, Lonardi, S., Santos, J., Ndeve, A., Batieno B.J., Boukar, O., Cisse, N., Drabo, I., Fatokun, C., Kusi, F., Agyare, R.Y., Guo, Y.-N., Herniter, I., Lo, S., Wanamaker, S.I., Close, T.J., Roberts, P.A., 2016. A multiparent advanced generation inter-cross population for genetic analysis and breeding in cowpea (*Vigna unguiculata* L. Walp.). The Plant Journal (submitted July 2017, under revision).

Kusi, F., Padi, F.K., Obeng-Ofori, D., Asante, S.K., Agyare, R.Y., Sugri, I., Timko, M.P., Koebner, R., Huynh, B.L., Santos, J.R.P., Close, T.J., Roberts, P.A. 2017 A novel aphid resistance locus in cowpea identified by combining SSR and SNP markers. Plant Breeding (Submitted to, May, 2017, under minor revision).

Santos, J.R.P., Ndeve, A., Huynh, B.L., Matthews, W.C., Roberts, P.A. 2017. Transcriptome analysis of cowpea near-isogenic lines reveals candidate genes for root-knot nematode resistance. PLoS ONE (Submitted to, August, 2017, under revision).

Roberts, P. A., Huynh, B.L., Frate, C.A. 2017. Blackeye improvement. University of California Dry Bean Research Annual Progress Report 2016. 1-8.

Burridge, J., Schneider, H. M., Bao-Lam Huynh B. L., Roberts P.A., Bucksch A., Lynch J.P. 2017. Genome-wide association mapping and agronomic impact of cowpea root architecture. Theoretical and Applied Genetics 130(2): 419-431 DOI 10.1007/s00122-016-2823-y.

Sun, W., Huynh, B.-L., Ojo, J.A., Brad S. Coates, B.S., Kusi, F., Roberts, P.A., Pittendrigh, B.R. 2017. Comparison of complete mitochondrial DNA sequences between old and new world strains of the cowpea aphid, *Aphis craccivora* (Hemiptera: Aphididae). Agri Gene 4: 23-29. doi:10.1016/j.aggene.2017.03.003.

Boukar O., Fatokun C. A., Huynh B.L., Roberts P.A., Close T.J. 2016. Genomic tools in cowpea breeding programs: status and perspectives. Frontiers in Plant Science 7:757 (pp 1-13). doi: 10.3389/fpls.2016.00757

Ndiaye M., Sarr M.P., Cisse N., Ndoye I. 2015. Is the recently described *Macrophomina pseudophaseolina* pathogenically different from *Macrophomina phaseolina*? African Journal of Microbiology Research 9(45):2232 -2238. DOI: 10.5897/AJMR2015.7742.

Lalsaga W.J.A., Nana R., Sawadogo M., Sawadogo N., Kiebre M., Drabo I. 2016. Field assessment of ten cowpea genotypes [*Vigna unguiculata* (L.) Walp.] for drought tolerance. International Journal of Innovation and Applied Studies 14(4):1005-1014. ISSN 2028-9324.

Batieno B.J., Danquah E., Tignegre J.B., Huynh B.L., Drabo I., Close T.J., Ofori K., Roberts P.A., Ouedraogo T.J. 2016. Application of marker-assisted backcrossing to improve cowpea (*Vigna unguiculata* L. Walp) for drought tolerance. Journal of Plant Breeding and Crop Science 8: 273-286. DOI: 10.5897/JPBCS2016.0607. ISSN 2006-9758, 273-286.

Muñoz-Amatriaín M, Mirebrahim H, Xu P, Wanamaker SI, Luo M, Alhakami H, Alpert M, Atokple I, Batieno BJ, Boukar O, Bozdag S, Cisse N, Drabo I, Ehlers JD, Farmer A, Fatokun C, Gu YQ, Guo Y-N, Huynh BL, Jackson SA, Kusi F, Lawley CT, Lucas MR, Ma Y, Timko MP, Wu J, You F, Roberts PA, Lonardi S, Close TJ (2016) Genome resources for climate-resilient cowpea, an essential crop for food security. The Plant Journal. DOI: 10.1111/tpj.13404. Pp.1-13.

Batieno B.J., Tignegre J.B., Sidibé H., Zongo H., Ouedraogo T.J., Danquah E., Ofori K. 2016. Field Assessment of Cowpea Genotypes for Drought Tolerance. International Journal of Sciences: Basic and Applied Research 30(4): 358-369. ISSN 2307-4531

Barro A., Batieno B.J., Tignegre J.-B., Dieni Z., Sidibe H., Sawadogo M. 2017. Diallel analysis of cowpea populations for resistance to cowpea aphid-borne mosaic virus disease (CABMV) in Burkina Faso. Journal of Plant Breeding and Crop Science 9(7): 90-97.

Conference Paper Abstracts

1. Kusi, F. 2016. Participatory Integrated Pest Management for Increased Cowpea Production in Northern Ghana. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
2. Tetteh Kubi, G., Botchey, M., Asare T.A., and Kusi, F. 2016. Improving the Field Resistance of Cowpea Genotypes to Cowpea Aphid. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
3. Poda L.S., Kusi F. Akromah R., Ouedraogo T.J., Tignegre J.B., Batieno J. 2016. Genetic Mapping of Striga and Thrips Resistance in Cowpea Population in Northern Ghana. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
4. Agyeman-Duah G., Kusi F., Opoku N. 2016. Genetic Relatedness of Cowpea Aphid Resistance. Proceedings of Joint 2016 Pan African Grain Legume and

World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.

5. Attamah P., Akromah R., Kusi F., Nyadanu, D. 2016. Screening and Genetic Studies of Drought Tolerance among SARI Favourite Cowpea Lines. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
6. Owusu Y. E., Akromah R., Kusi F., Denwar. N. 2016. Inheritance of Extra-Early Maturity in Cowpea. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
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Poda, S. L. 2016. Phenotyping for *Striga gesnerioides* and *Megalurothrips sjostedti* resistance in cowpea populations in Northern Ghana. M.Phil. Thesis, Kwame Nkrumah University of Science and Technology, 116 p.

X. Achievement of Impact Pathway Action Plan

Under Objective 1, the primary thrust of the impact pathway progress centers on identifying QTLs determining traits for insect tolerance and resistance. As described in the technical section under Objective 1, this involves a combination of phenotype screening in the target areas (combination of greenhouse and field-based screens), together with high-throughput SNP genotyping with genomewide markers and followed by ICI-mapping to identify significant QTLs. The various populations for QTL discovery are at different stages of this process and require multi-year and multi-location data collection from the phenotyping trials.

Under Objective 2, the primary impact pathways are release of new cowpea varieties. As reported in the technical section, five all-white large seeded varieties (Lisard, Thieye, Leona, Kelle and Sam) were released in Senegal in 2015, and entered the seed development pipeline with Breeder and Foundation seed production in 2015 - 2017. In Burkina Faso, a set of four white-seed pre-release advanced lines are still awaiting formal release action by the national variety release committee. Meanwhile in anticipation of release, Breeder Seed was produced by INERA in 2015, 2016 and 2017. In California, advanced breeding lines are in different advanced stages of final testing, which in 2016 and 2017 included large-scale strip-trial testing and warehouse processing using five different farmer production fields in the San Joaquin Valley. These data will help to determine decisions on variety releases for the US blackeye cowpea market.

ANNEXES

Table 1: Summary of cowpea aphid resistance responses of the differential panel for determining resistance uniqueness and aphid biotype differences across five countries. (R = resistant; MR = moderately resistant; S = susceptible.

Cowpea line	**Burkina**	**Senegal**	**Ghana**	**Nigeria**	**Cal-USA**
58-77	MR	R	R	R	MR
INIA19	R	R	--	S	R
IT97K-556-6	R	--	R	R	R
KN1	R	R	--	S	S
KvX-295-2-124-99	R	R	R	S	R
SARC-1-57-2	R	MR	R	R	S
TVNu-1158	--	--	--	R	R
APAGBAALA	S	S	S	MR	S
BAMBEY21	S	S	S	MR	S
CB27	S	R	R	S	S
IT82E-18	S	S	S	S	S

Table 2. Grain yield and 100-seed weight of new blackeye breeding lines and checks tested at Kearney REC in 2016. Root-galling ratings from 2014 field screening with root-knot nematodes *M. incognita, M. javanica,* and *M. incognita* Muller; Fusarium wilt Race 4 disease index from 2014 greenhouse screening.

Entry	Yield (lb/ac)	100-seed wt (g)	Galling *M. incognita*	Galling *M. javanica*	Galling *M. incognita* Muller	Fusarium Race 4 index
CB46	3354	21.4	1.6	3.4	4.2	4.9
2014-008-51-82	3321	21.3	-	-	-	-
N2	3256	21.3	1.2	1.2	3.8	0.2
2014-008-51-77	3234	20.5	-	-	-	-
N5	3213	21.1	0.8	1.5	3.5	0.8
2014-008-51-89	3027	20.7	-	-	-	-
2014-010-41-25	2995	24.7	-	-	-	-
CB46Rk2	2919	21.2	1	2.7	2.9	0.0
10K-29	2875	22.6	2.4	2.9	4.2	0.0
2014-010-41-69	2853	25.0	-	-	-	-
CB50	2733	24.9	-	-	-	0.0
2014-010-41-47	2320	24.8	-	-	-	-
Mean	3008	22.4				
CV%	14	3				
LSD(0.05)	617	0.9				

Trial planted June 8, cut October 17 (131 days), machine-harvested October 31.
Root-galling score on scale of 0 (no galling) to 8 (severe galling).
Fusarium wilt disease index (0 to 5; where 0 = no wilt symptoms and 5 = plant death).

Table 3: Results of Chi-square test for F2 segregation of resistance to *C. tomentosicollis* (pod-sucking bug) in Burkina Faso.

Number of F_2	Number of resistant observed	Number of susceptible observed	Number of resistant expected	Number of susceptible expected	Ratio	X^2 (ddl=1)[a]	P
70	28	42	35	35	1 : 1	2,8	0,05

Table 4: Breeding populations and lines of Dr. Cisse in 2017 preliminary yield trials in Senegal.

Pedigree	**Traits of interest**	**Donor**	**Generation**
Melakh x IT97K-499-39	Striga	IT97K-499-39	F2
3211 x IT97K-499-39	Striga	IT97K-499-39	F2
Melakh x (Melakh x IT97K-499-39)	Striga	IT97K-499-39	BC3F3
Pakaw x (58-77 x Sanzi)	Thrips	Pakaw	F5
3178 x (58-77 x Sanzi)	Thrips	3178	F5
(Melakh x Yacine) x Yacine	Resistance multiple	Melakh	F5
(Melakh x Yacine) x Melakh	Resistance multiple	Yacine	F5
Melakh x Yacine	Resistance multiple	Yacine	F6
(Melakh x 3217) x Melakh	Grain quality	3217	F5
(Melakh x 3211) x Melakh	Grain quality	3211	F5
(Yacine x 3217) x Yacine	Grain quality	3217	F5
(Yacine x 3211) x Yacine	Grain quality	3211	F5
Melakh x 3178	Grain quality	3178	F6
Melakh x 3201	Grain quality	3201	F6
Melakh x 3205	Grain quality	3205	F6
Melakh x 3211	Grain quality	3211	F6
Melakh x 3217	Grain quality	3217	F6
Yacine x 3205	Grain quality	3205	F6
Yacine x 3217	Grain quality	3217	F6
Mouride x Yacine	drought	Yacine	F6
Suvita2 x IT93K-503-1	drought	IT93K-503-1	F6

Table 5: Breeder's Seeds of new and current cowpea varieties produced in Senegal in 2017.

Varieties	**area (m^2)**	**Breeder**	**Period**	**Production (kg)**
Kelle	2500	G0	Off season	20
Kelle	5000	G0	Rainy season	287
Leona	2500	G0	Off season	146
Leona	5000	G0	Rainy season	127
Lizard	2500	G0	Off season	115
Lizard	5000	G0	Rainy season	314
Melakh	2500	G0	Off season	437
Melakh	5000	G0	Rainy season	306
Sam	2500	G0	Off season	96
Sam	5000	G0	Rainy season	353
Thieye	2500	G0	Off season	204
Thieye	5000	G0	Rainy season	289
Yacine	2500	G0	Off season	338
Yacine	5000	G0	Rainy season	214

Table 6. New blackeye lines and check CB46 tested in 4 grower production field strip trials in Tulare Co. in 2016.

Parameter	Trial I	Trial II	Trial III	Trial IV
Area (ac)	0.558	0.558	0.388	0.455
Yield (lbs/ac)				
N2	5784	6074	1517	2174
CB46	5639	6074	1543	1894
CB46-Rk2	5639	6123	1202	2112
10K-29	5058	6268	1289	1304
100-seed wt (g)				
N2	18.7	19.1	19.4	21.0
CB46	19.2	19.4	19.6	20.3
CB46-Rk2	17.4	16.7	19	21.5
10K-29	17.4	19.7	20.8	23.0

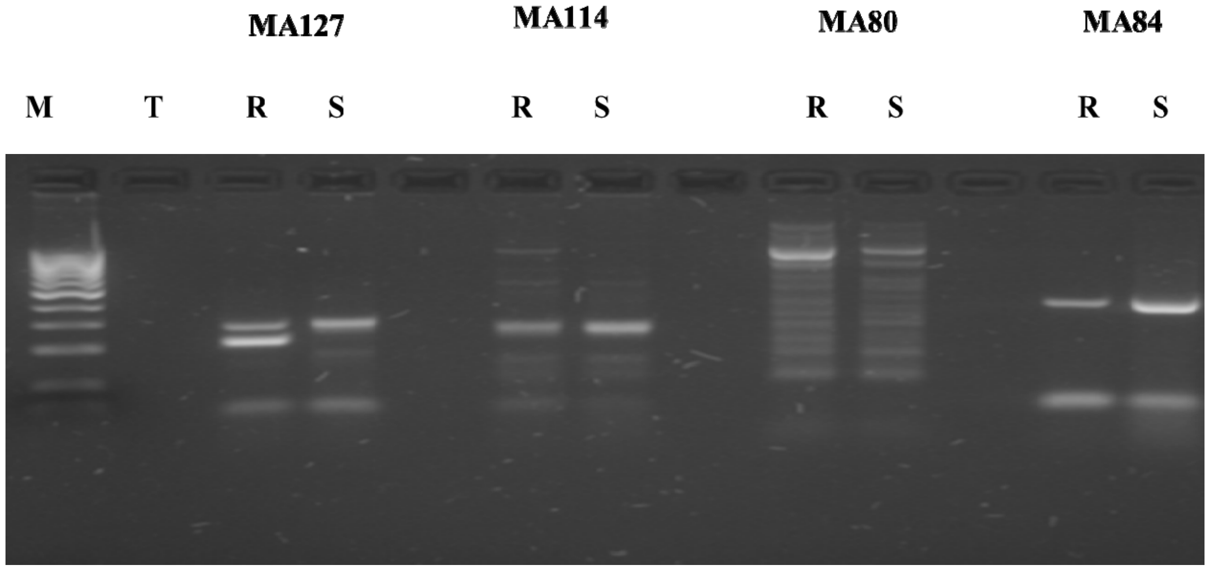
Trial I planted May 11, cut September 23, harvested October 6 (148 days)
Trial II planted May 25, cut September 26, harvested October 11 (139 days)
Trial III planted May 28, cut August 18, harvested September 4 (99 days)
Trial IV planted June 25, cut October 4, harvested October 25 (122 days)

Table 7. Grain yield, 100-seed weight, and lygus grain damage of 2 advanced blackeye lines and CB46 when grown under insect-unprotected conditions at Kearney REC in 2016..

Entry	Yield (lb/ac)	100-seed wt (g)	Lygus damage (%)
07KN-74	2485	23.0	27
N2	2138	20.0	27
CB46	2138	19.7	29
Mean	2254	20.9	28
CV%	5	2	15
LSD(0.05)	251	1.0	9

Trial planted June 8, cut October 17 (131 days), machine-harvested October 31.

Figure 1: Screening method used for phenotyping for resistance to pod-sucking bugs (*C. tomentosicollis*) trial at Kamboinsé, Burkina Faso.



M : marqueur de poids moléculaire de référence de pas égal à 50pb.

T: Témoin

Voltage: 75 V; Temps de migration: environ 1heure

Gel d'agarose de concentration 2%.

Figure 2. Banding profiles of four SSR markers tested for linkage to resistance to pod-sucking bugs (*C. tomentosicollis*), Kamboinsé, Burkina Faso.

Figure 3. Damage caused by pod-sucking bugs (*C. tomentosicollis*) on cowpea pods and seeds in Burkina Faso.

Figure 4. Women dominated cowpea farmers based organization (FBOs) at a field day and training in IPM for cowpea production at Manga station during 2017 cropping season.

Figure 5. On-farm training of Agricultural Extension Agents (AEAs), FBOs and seed producers in seed production and the use of host plant resistance in effective pest management during 2017 cropping season.

Figure 6. Training of cowpea farmers in good agricultural practices for profitable cowpea production.

Figure 7. Training of agricultural science students from Bawku Senior High School (Bwaku SHS) in identification of the major insect pests of cowpea and their management strategies.

Figure 8. Practical training of agricultural science students from Bawku Senior High School (Bwaku SHS) and their teachers in breeding method to combine aphid and striga resistance in farmer preferred cowpea varieties.

Figure 9. Teaching of agricultural science students from Bawku Senior High School (Bwaku SHS) and their teachers in principles of host plant resistance

Feed the Future Innovation Lab for Collaborative Researchon Grain Legumes

Report on the Achievement of "Milestones of Progress"

(For the Period: October 1, 2016-- March 31, 2017)

This form should be completed by the U.S. Lead PI and submitted to the MO by April 1, 2017

Project Title: **SO1.A5 Genetic improvement of cowpea to overcome biotic stress and drought constraints to grain productivity**

	Abbreviated name of institutions																	
	UC-Riverside			INERA B. Faso			ISRA Senegal			SARI Ghana			Institution 5			Institution 6		
	Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved	
Milestones by Objectives	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *
	(Tick mark the Yes or No column for identified milestones by institution)																	
Objective 1	**Breeding and Trait Discovery - Aphid Resistance**																	
1.1.1 insect samples collected	x	x		x	x		x	x		x	x		0			0		
1.1.2 Validate differential test	0			0			0			0			0			0		
1.1.3 phenotype progenies	0			0			0			0			0			0		
1.1.4 genotype progenies	x	x		x	x		x	x		x	x		0			0		
1.1.5 QTL mapping resistance	0			0			0			0			0			0		
Objective 1:2	**Breeding and Trait Discovery -Flower Thrips Resistance**																	
1.2.1 phenotype RILs for QTL	0			0			0			0			0			0		
1.2.2 insect samples collected	0			0			x	x		x	x		0			0		
1.2.3 phenotype F7 populations	0			0			0			x	x		0			0		
1.2.4 QTL mapping resistance	x	x		0			x	x		x			0			0		
0	0			0			0			0			0			0		
Objective 1:3	**Breeding and Trait Discovery Pod-sucking Bug Resistance**																	
1.3.1 phenotype IT86D-716 popns	0			x	x		0			0			0			0		
1.3.2 insect samples collected	x	x		x	x		0			0			0			0		
1.3.3 advance to F3 from 1.3.1	0			0			0			0			0			0		
1.3.4 genotype F2; plus F3 from 1.3.3	x	x		x	x		0			0			0			0		
1.3.5 QTL discovery - ICI mapping	0			0			0			0			0			0		
Objective 2:	**Breeding and Trait Discovery SNP Markers for Bt tracking and variety release**																	
2.1.1 genotype Bt populations	x	x		x	x		x	x		0			0			0		
2.2.1 foundation seed of releases	0			x		x	0			0			0			0		
2.2.2 on-farm test & Breeder Seed	0			x	x	x	0			0			0			0		
2.2.3 advanced yield trials	0			x	x		0			0			0			0		
0	0			0			0			0			0			0		
Name of the PI reporting on milestones by institution	P. Roberts			J. Batieno			N. Cisse			F. Kusi			PI name			PI name		

Name of the U.S. Lead PI submitting this Report to the MO: P. Roberts

Signature: [signature]

Signature

#####

Date

* *Please provide an explanation for not achieving the milestones on a separate sheet.*

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes
REVISED PERFORMANCE INDICATORS / TARGETS SPREADSHEET for FY 14, FY 15, FY16, and FY 17

Project Name:

Institution Name (one sheet per institution):

Indic. number	Output Indicators	FY 14 Target	FY 14 Revised	FY 14 Actual	FY 15 Target	FY 15 Revised	FY 15 Actual	FY 16 Target	FY 16 Revised	FY 16 Actual	FY 17 Target	FY 17 Revised	FY 17 Actual	FY18 Target	FY 18 Revised	FY 18 Actual
		(October 1, 2013 - September 30, 2014)			(October 1, 2014 - September 30, 2015)			(October 1, 2015 - September 30, 2016)			(October 1, 2016 - September 30, 2017)			(Oct 1, 2017 - Nov 30, 2017)		
1	4.5.2(6) Degree Training: Number of individuals who have received degree training	10	4	7	11	12	12	11	12	0	12	15	15	11	11	11
	Total number by sex	10	4	7	11	12	12	11	12	13	12	15	15	11	11	11
	Number of women	5	2	4	5	5	5	5	4	5	5	4	7	4	4	4
	Number of men	5	2	3	6	7	7	6	8	8	7	8	8	7	7	7
	Total number by New/Continuing	10	4	7	11	12	12	11	12	13	12	15	15	11	11	11
	New	5	2	4	5	5	5	5	4	7	5	5	6	4	4	4
	Continuing	5	2	3	6	7	7	6	8	6	7	10	9	7	7	7
2	4.5.2(7) Short-term Training: Number of individuals who have received short-term	631	333	638	1910	1907	2045	2520	2760	2820	4360	4640	4668	668	668	668
	Total number by sex	631	333	638	1910	1907	2045	2520	2760	2820	4360	4640	4668	668	668	668
	Number of women	296	116	291	659	663	878	963	1030	1208	1753	2298	2331	431	431	431
	Number of men	335	217	347	1251	1244	1167	1557	1710	1612	2607	2342	2337	237	237	237
	Number by Type of individual	631	333	638	1910	1907	2045	2520	2760	2820	4360	4640	4668	668	668	668
	Producers	480	270	434	1670	1670	1790	2145	2380	2408	3440	3640	3680	434	434	434
	Number of women									1015		1760	1870	294	294	294
	Number of men									1393		1880	1810	140	140	140
	People in government	39	27	38	110	110	120	120	140	122	400	440	450	111	111	111
	Number of women									55		212	207	37	37	37
	Number of men									67		228	243	74	74	74
	People in private sector firms	24	16	26	78	85	60	185	205	215	385	395	345	81	81	81
	Number of women									109		192	142	60	60	60
	Number of men									106		173	203	21	21	21
	People in civil society	38	20	40	52	42	45	60	55	75	155	195	193	44	44	44
	Number of women									32		85	83	30	30	30
	Number of men									43		110	110	14	14	14
7	4.5.2(39) Number of new technologies or management practices in one of the following phases of development: (Phase I/II/III)									289	282	432	433	416	416	416
	Phase 1: Number of new technologies or management practices under research as a result of USG assistance	97	68	97	153	128	167	172	172	172	180	340	340	331	331	331
	Phase 2: Number of new technologies or management practices under field testing as a result of USG assistance	40	20	40	39	24	42	51	51	101	66	66	68	63	63	63
	Phase 3: Number of new technologies or management practices made available for transfer as a result of USG assistance	8	0	8	10	2	10	15	15	16	26	26	25	22	22	22

Notes:
These indicators are developed under the Feed the Future Monitoring System. Please provide 'total' numbers and also disaggregate where applicable. Just providing 'totals' will not be approved.
This table corresponds to the Feed the Future Performance Indicators data collection sheet under the FTFMS system. Where an indicator does not apply to the type of work done under the project, leave it blank.
Please follow the indicators in the Legume Innovation Lab Indicators Handbook that will be provided to you by the Management Office. Contact Mywish Maredia (maredia@anr.msu.edu) for further information.
There is additional guidance on the USAID/Agrilinks website: http://agrilinks.org/sites/default/files/resource/files/FY14%20FTFMS%20Guidance_2.pdf

VIII. IPM-omics: Scalable and Sustainable Biological Solutions for Pest Management of Insect Pests of Cowpea in Africa (SO1.B1)

Lead U.S. Principal Investigator and University:

Dr. Barry Pittendrigh, Michigan State University (July 16, 2016-Present) and previously at University of Illinois at Urbana-Champaign (UIUC)

Dr. Kenneth Paige (managing sub-contracts to HC partners), University of Illinois at Urbana-Champaign (UIUC) (July 16, 2016-Present)

Collaborating Host Country and U.S. PIs and Institutions:

Dr. Manuele Tamò, IITA-Benin (HC-PI)

Drs. Clémentine Dabiré-Binso and Fousséni Traore, INERA-Burkina Faso (HC-PI)

Mr. Laouali Amadou, INRAN-Niger (HC-PI) (Replacement for Dr. Ibrahim Baoua with Dr. Baoua still collaborating with our team)

Dr. Ibrahim Baoua, University of Maradi (collaborator with INRAN; funding goes through INRAN)

Dr. Stephen Asante, SARI, Ghana (HC-PI)

Dr. Moses Mochiah (Replacement for Dr. Haruna Braimah with Dr. Braimah still collaborating with our team), CSIR-CRI- Ghana (HC-PI)

Dr. Julia Bello-Bravo, UIUC (US Co-PI)

Mr. Eustache Biaou, INRAB-Benin (HC-PI) (Replacement for Mr. Leonard Hinnou)

I. Abstract of Research and Capacity Strengthening Achievements

Over the past year we have continued to push forward our understanding of and solutions for the major pests of cowpeas in four West African countries: Benin, Niger, Burkina Faso, and Ghana. Specifically, we have characterized pest populations through molecular tools, with a specific focus on mitochondrial polymorphisms. Solutions to these pest problems have been developed and pushed forward. These include across-country releases of biocontrol agents and a larger scale testing of neem and *Maruca*-specific viral combined sprays. We have also continued to investigate the use of educational tools, involving animations voice overlaid into local languages, as a scalable

system to deploy the outcomes of our research efforts to create and deploy locally sourced pest control solutions. Our capacity building efforts have included undergraduate and graduate training efforts in the host country programs, cross training of technicians across countries, and we have continued to test our animated educational approach, including ICT training sessions and feedback on our Android App allowing collaborating organizations to easily access and use these materials in their educational programs. We have continued to collaborate with Dr. Maredia's team at MSU and Dr. Mazur's team at ISU towards social science-oriented questions relating to scaling out technologies and approaches for pass-off to other groups.

II. Project Problem Statement and Justification

Insect pests of cowpeas dramatically reduce yields for cowpea farmers in West Africa, many of who live on less than several USD per day. The greatest biotic constraints on cowpea (*Vigna uguiculata* [L.] Walp.) production are insect pests. The major pests of cowpea in the field in northern Nigeria, in Niger, Ghana, and in Burkina Faso include: (i) the legume pod borer, *Maruca vitrata* Fabricius; (ii-iii) the coreid pod-bugs, *Clavigralla tomentosicollis* Stäl and *Anoplocnemis curvipes* (F.); (iv) the groundnut aphid, *Aphis craccivora* Koch; and, (v-vi) thrips, *Megalurothrips sjostedti* Trybom. Our program is focused on a three-step approach for (1) defining the pest problems, (2) developing appropriate pest control solutions and (3) developing strategies for scaling of these solutions. We have continued to develop an in depth understanding of the pest populations through a combination of field experiments and molecular tools to characterize and compare pest populations. We have developed solutions that have and will allow for the development of local cottage industries that can produce biopesticides for local sale and use – thereby facilitating the potential for local value chains that result in the development and sale of ecologically friendly pest control solutions. These efforts are already being realized with local neem production businesses in Benin. We have continued to investigate biological control agents in our biocontrol pipeline and promising candidates have been released in the field, through approaches we have developed to scale their release in a cost-effective manner. Additionally, we have (1) developed scalable educational solutions to train people in many of the pest control strategies in their own languages and for all literacy levels, (2) we have experimental data showing people learn the same or more from the animations than from traditional extension presentations, and (3) we have explored pathways for passing these off to other groups that can deploy these in their educational programs. Finally, in terms of capacity building, we (1) have been working with NGOs and local communities for pass off of our outcomes, (2) we have continued undergraduate and graduate training, and (3) a cross-country technician training program to facilitate capacity in biocontrol agent rearing and release as well as biopesticide development, deployment and pass-off to local commercial and non-commercial entities.

III. Technical Research Progress

Over the past 12 months we have researched, developed, implemented and performed and analyzed datasets around determining the potential for impacts of our strategies for cowpea farmers in West Africa. We have continued to research and develop scalable solutions, with the potential and actualization of larger-scale impact through donor community buy-in. However, it is critical to note that our project has moved to the point where implementation has become a greater focus. As part of that donor community buy-in the Bill and Melinda Gates Foundation has funded outcomes of our past efforts on *Maruca* – the objectives of that grant do not overlap with the current USAID Legumes Innovations Lab grant. Our objectives emerge from the following vision, with three critical major objectives, supported and intertwined with the fourth objective of capacity building. We term this approach IPM-omics – as a system to develop and deploy scalable solutions.

First, we define IPM-omics in the following "equation":

IPM-omics = ***define the pest problems*** + ***appropriate solutions*** + ***scaling of solutions***

In the below objectives and outcomes we outline how we have actualized each of these steps with institutional capacity building being integral to this overall process. Below are given our four objectives and our accomplishments under those objectives.

Objective 1. Define the pest problems: (1) scouting, field experiments, and light traps; (2) genomic markers to define pest and biocontrol agent populations – movement patterns and sources of the outbreaks; (3) computational modeling; and, (4) understanding the biology of pest populations to drive pest controls strategies.

1.1 Scouting and field experiments

The IITA, INERA, INRAN, CRI, and SARI teams all continue to perform efforts to understand pest populations during the cowpea cropping cycles and outside of these cycles. Insects found on diverse alternative host plants are stored in RNA later or 70% ethanol to be sent to UIUC for molecular analyses. Additionally, the INERA team has continued their experiments on understanding the pest populations that occur in the dry season in places where an extra cycle of cowpea could occur where irrigation by some farmers is possible.

1.2 Molecular Analyses of pest populations

From IITA, UIUC/MSU has continued to receive pest populations for molecular analysis of insects that have been collected from numerous host plant populations, for all species tested, across Benin, Niger, Burkina Faso, and Ghana. The specimens have been stored at -80^{o}C and the DNA extracts have been shipped to UIUC/MSU for further molecular analyses. Similar sample collections of insects have been received from our teams in Burkina Faso, Niger, and Ghana. Molecular analyses (SNP and microsatellite analyses) have continued at UIUC and are now continuing at MSU. However, this past year we have focused more intensely on SNP analysis of mitochondrial genes as we have developed a protocol that allows us to determine the relationships between the populations that will be more useful in the future. One additional series of experiments include populations of aphids collected by the UC-Riverside team (Dr. Phil Roberts) on different lines of cowpeas. We published the paper in 2017 on these collaborative efforts with Dr. Phil Roberts and his research team.

1.3 Computational Modeling, GIS systems and Online System

The UIUC/MSU and IITA teams have continued to work on a flowchart system that will be used in predictive responses to when and where cowpea farmers can or should intervene in pest control strategies. The IITA team continues to use modeling approaches with the graduate students under Dr. Tamo's direction to better characterize pest populations. The IITA and UIUC/MSU teams are continuing to explore the use of GIS systems to couple our other datasets with GIS data.

The UIUU/MSU has focused on making sure all educational output from the SAWBO animations are readily available for online download from the SAWBO system.

1.4 <u>Insect biology - Sex and aggregation pheromones for pod sucking bugs</u>

IITA has continued collaborating with *icipe,* Nairobi, Kenya (Baldwyn Torto) and Nort-West University, Potchefstroom, South Africa (Johnnie van der Berg) to elucidate putative male aggregation pheromones of the coreid bug *Clavigralla tomentosicollis* and its interactions with the egg parasitoids *Gryon fulviventre*, as part of a PhD study carried out by a student who has been awarded an *icipe*-ARPPIS PhD fellowship to investigate the chemical ecology of this pest group (including *Clavigralla* spp. from West and East Africa).

In 2017, major breakthroughs were the identification of both aggregation and sex pheromones emitted by both sexes of *C. tomentosicollis*, with strongest activity of aggregation pheromones being produced in the thorax of males. Draft chemical formulas of the aggregation pheromone compounds have been identified and are being further characterized. Right now, the student is assaying these compounds on the attractiveness of foraging female egg parasitoids *G. fulviventre* using olfactometric testing.

He has also started identifying different *Clavigralla* spp. in West and East Africa, inferring the population genetic variability of the most dominant *Clavigralla* spp., as well as comparing genetic data (PCR amplification using COI & ITS2) with pheromone profiles.

Objective 2. Appropriate solutions. We have developed a biocontrol and biopesticide pipeline, in order to develop a series of environmentally and economically appropriate pest control solutions.

2.1. <u>Novel *Maruca* parasitoids available for screening</u>

As part of a joint PhD fellowship with the University of Montpellier, France, (Anne-Nathalie Volkoff, UMR DGIMI) and the University of Abomey Calavi, Benin, (Aime Bokonon-Ganta, UAC-FSA), we have continued investigating maternal factors responsible for the parasitization success in *T. javanus*, one of the best biocontrol candidates against the pod borer *M. vitrata*.

Major highlights in 2017 were the investigation of ovary morphology and anatomy, oogenesis, potential fecundity and egg load in *T. javanus*, as well as the effect on egg load of factors as age of the female parasitoid/host size at oviposition. The reproductive tract of *T. javanus* females presented a classical basic morphological organization, with ovarioles from the polytrophic meroistic type, similar to what has been described in other Braconids. The study also showed that *T. javanus* is synovigenic, *i.e.*, that teneral females emerge with comparatively few mature eggs and continue to produce eggs throughout the adult stage. In addition, oocytes at different development stages were observed in the ovarioles of females of various ages, suggesting that *T. javanus* may be able to regulate egg load depending on host availability. The number of ovarioles was found variable and significantly influenced by the age/size of the *M. vitrata* host when parasitized. Egg load also was strongly influenced by both the instar of *M. vitrata* caterpillar at the moment of parasitism as well as wasp age. These findings have practical implications for improving the mass rearing methodology for *T. javanus* and were published in a peer reviewed journal article (see publication list).

We have also investigated how volatiles from different cultivated and wild-occurring host plants used by *M. vitrata* can influence olfactory responses of foraging female parasitoids *T. javanus*. First, we used an observation arena monitored by a high sensitivity digital camera, and recorded videos were analyzed using dedicated Noldus Observer software. Also, the response of foraging *T. javanus* females to volatiles produced by flowers and/or pods of *V. unguiculata*, *L. sericeus*, *S. rostrata* and *T. platycarpa* was tested using a glass Y-tube olfactometer. Results are currently being summarized and a draft paper is in preparation.

2.3 PCR techniques for detecting endophytic strains of *Beauveria bassiana* available

We have continued investigating different techniques and methodologies for detecting entophytic *Beauveria bassiana* in cowpea vascular tissue.

A new study was carried out in 2017, comparing more recently collected (from Benin) lepidopteran-active isolates of *B. bassiana* to the standard Bb115 (of Malagasy origin) we have been using so far. This study confirmed earlier results with Bb115, but also demonstrated much higher colonization rates of cowpea flowers after leaf inoculations, particularly with Bb7. The high level of colonization observed in these two tissues (leaves and flowers) could be an asset in the development of cowpea pest control mechanism.

Table 1: Percentage colonization of cowpea organs by endophytic isolates of *Beauveria bassiana* using foliar and seed inoculation

Inoculation method	Organ	*Beauveria bassiana* isolate						
		Bb2	Bb7	Bb11	Bb12	Bb13	Bb14	Bb115
Foliar	Root	4±4 ab	8±4,89a	28±18,54a	0a	12±8a	0a	4±4a
	Stem	8±4,89b	8±8a	12±8a	0a	0a	4±4a	12±8a
	Leaf	8±4,89b	12±4,89a	4±4 a	4±4a	0a	12±8a	16±4a
	Flower	0 a	44±19,39b	4±4a	8±8a	4±4a	0a	12±8a
Seed	Root	8±4,89a	0a	8±4,89a	0a	0a	16±9,79a	0a
	Stem	4±4a	0a	16±7,48a	0a	0a	8±8a	0a
	Leaf	4±4a	4±4a	8±8a	4±4a	4±4a	16±9,79a	16±11,66a
	Flower	4±4a	24±14,69a	12±8a	0a	4±4a	4±4a	4±4a

Using PCR protocol and DNA extracted from surface-sterilized leaf, root and stem sections of cowpea plants inoculated with *B. bassiana* conidia both using seed and foliar inoculation, we were able to observe clear fingerprints of the endophyte after electrophoresis on gel agarose. All samples that were subjected to the PCR test were positive and the amplicon obtained from the different tissues showed the same molecular weights at 2kb.

2.3 Genetic improvement of cowpea to overcome biotic constraints to grain productivity (in collaboration with the UCR cowpea breeding team):

A manuscript is current being prepared between the UIUC/MSU and URC regarding biotype differences between cowpea aphids. We expect to submit the manuscript in the spring of 2017.

Objective 3. Scaling of solutions. When solutions have been developed we need mechanisms to effectively deploy them in a cost effective and sustainable manner. Discovering and testing such scaling pathways will be critical to determine which approaches will be most successful for scaling. Solutions, for scaling, fall into three categories: (3.1) direct release into the environment and natural establishment; (3.2) educational solutions; and (3.3) private sector and NGO involvement.

3.1.1. *Maruca* parasitoids (IITA)

After last years' massive releases of 32,000 *Therophilus javanus* and 17,600 *Phanerotoma syleptae* in Benin and 16,200 *T. javanus* and 10,500 *P. syleptae* in Burkina Faso, in 2017 we concentrated our efforts in documenting establishment of both parasitoids on wild alternative host plants and cowpea crops. In Benin, some 397 samples from 42 different localities were collected from major host plant such as *Pterocarpus santalinoides, Millettia thonningii, Lonchocarpus sericeus, L. cyanescens, Tephrosia* spp. and *Sesbania* spp., in addition to cowpea crops.

By and large, both parasitoids were recovered throughout the release areas in Benin, at distances up to 23 km from the original release sites, less than one year after the release. In fact, surveys carried out in Benin in February–April 2017 indicated with certitude and unambiguously that both species have successfully survived the long dry season (particularly harsh this year) on alternative host plants in the absence of cowpea, nearly one year after initial experimental releases. While it is too early to be able to give a proper quantitative assessment of the impact of the released parasitoids on *M. vitrata* populations, it is noteworthy that during the recent post-dry season surveys we were able to recover parasitized *M. vitrata* larvae from very low pod borer populations, indicating a good ecological adaptation of both parasitoids, and maybe also an early sign of parasitoid efficacy.

A few more releases were carried out in Benin and Burkina Faso (total of 9,600 and 6,800 *T. javanus,* and 18,700 and 8,000 *P. syleptae,* respectively), and new releases were also carried out with INRAN at Maradi, Niger (3,000 *Therophilus javanus* and 1,500 *Phanerotoma syleptae*)

These preliminary data have allowed us to refine our strategy for releasing parasitoids of *M. vitrata*. It relies on 5 pillars:

1. *Participatory releases with communities, regulatory authority and policy makers*

Many biological control campaigns are just focusing on releases of natural enemies without involving local populations who will be affected by the measure. It is therefore important to carry out the releases in participatory manner, in concomitance or shortly after a sensitization campaign (see below). IITA, CRI, SARI, and INRAB used part or a majority of their non-degree training resources for these efforts, however, interactions with individual groups/people were less than one day (per person interaction) and therefore do not fall under short-term training. INRAN and INERA also use part of their funding, of non-degree training resources, for these same types of efforts respectively in Niger and Burkina Faso. Equally important and also to respect current regulations, at each new site we have invited the regulatory authorities of the national plant protection and quarantine office, whenever possible together with the local (chef de village, chef d'arrondissement, maire) and traditional (chiefs and kings) authorities, and collaborators from the national agricultural research institutes (INRAB, universities).

2. *Sensitization campaigns prior or during releases*

A biological control campaign is the best opportunity to showcase the natural enemies and to explain to communities, in their local language. Using both SAWBO animations and 'wooden powerpoint slides' (using the visuals from the animations) on plywood boards, which explain in very simple terms a) the cowpea pest problem; b) the issue of pesticide use; c) basic biology of the pod borer; d) basic notions of biological control using the biology of the released hymenopteran parasitoids; and, e) the importance of alternative host plants for the survival of the natural enemies in the environment in the absence of cultivated cowpea during the off-season. Sensitization campaigns have been carried out at each of the release sites, in their local language, with close assistance by the local authorities.

3. *Targeting of season, agro-ecology and host plants: importance of Google Earth*

One of the most strategic issues in biological control is the appropriate choice of release sites. Prior to releases, Google Earth has proved to be a very useful tool for identifying hygromorphic areas suitable to harbor alternative host plants flowering during the long dry season, such as *Pterocarpus santalinoides*, *Lonchocarpus sericeus* and *Millettia thonningii*. All these plants are host for the pod borer during the off-season and will also serve as a dry-season reservoir for the released parasitoids.

4. *Fast releases using newly designed collapsible cages and pupae in bottles*

Another innovation how to be able to release high numbers of parasitoids in short time is the collapsible release cage. The cage can be opened on all sides thus allowing parasitoids to fly away immediately and reducing the release time for each cage from 30+ minutes to a few minutes. Hence, releasing 3,000-5,000 parasitoids can take less than one hour, compared to half a day before.

5. *Choice of recapture sites to determine establishment*

Here again we use data about the presence of alternative host plants during the dry season supported by satellite images from Google Earth. During the cowpea season, cowpea field are inspected in major cowpea cropping areas, taking care of avoiding crops heavily sprayed with synthetic pesticides.

These achievements were rendered possible by leveraging research funds from a separate grant by the Bill and Melinda Gates Foundation, for investigating a proof-of-concept of precision-IPM in cowpea.

We expect these parasitoids to establish on patches of wild vegetation where they were released, and produce several generations thereby increasing the population size and colonizing neighboring patches where host plants for *M. vitrata* are present. With the onset of the rainy season and the beginning of the cowpea cropping seasons, the parasitoids will follow the *M. vitrata* populations migrating to the cowpea fields. We anticipate an overall reduction of the *M. vitrata* damage in a range of 30–50% depending on prevailing local conditions (such as, e.g., rainfall pattern, planting dates, and cowpea varieties planted). This effort is part of an overall IPM strategy for controlling cowpea pests which includes the use of resistant varieties and the safe and judicious use of pesticides (which we are planning to substitute with locally produced bio-pesticides in the longer term), combined with modern ICT approaches to empower low-literacy farmers to make informed decisions about pest control options.

3.1.2. <u>Thrips parasitoid available for scaling up (IITA, INERA and INRAN)</u>

Also, this year we continued to supply adult individuals and pupae of the thrips parasitoids *Ceranisus femoratus* collected in Southern Benin on patches of leguminous trees in hygromorphic areas, which were subsequently hand-carried to the INERA labs at Farokoba, Burkina Faso, and released on host plants bearing high populations of flower thrips.

3.1.3. <u>Feasibility of storing *Maruca* virus both as liquid and solid substrate (IITA)</u>

After some negotiations, IITA has agreed to include the new pump of the freeze-dryer (9,000 USD) on the 2018 capital budget.

In the interim of having the powder form for the virus, in 2017 we made progress in having the first batches of the raw viral product (cadavers of virus-infected *M. vitrata* larvae produced by the women groups) sold to our labs for conditioning in order to be used for extensive field trials. The price of treating 1 ha with MaviMNPV has now been finalized with our partners, National University of Agriculture of Porto Novo and the social enterprise SENS-Benin, and it is close to 3 UDS/ha/treatment, which makes it very competitive compared to synthetic pesticides (ranging from 7 USD/ha for the cheapest and possibly unsuitable pesticides to over 15 USD/ha for the recommended insecticides).

3.1.4 <u>Scaling of the neem plus virus control strategies (IITA, INRAN and INERA)</u>

A pest control strategy which includes biological control as one of its pillars cannot be based on the indiscriminate application of synthetic pesticides as the forefront. In Benin, we have conducted demonstration trials with different biopesticides (neem, pod borer-specific virus and fungal biopesticide), and combinations thereof, which have resulted in the following information: a) against aphids and thrips we spray emulsifiable formulations of neem oil; b) against pod borers, in case of high infestation (*e.g.*, in areas not already colonized by the parasitoids) we spray either the virus or the fungal biopesticides, or their combination with emulsifiable neem oil; c) against pod sucking bugs, we spray emulsifiable neem oil or neem seed powder extract. Data in Benin shows evidence that *Maruca* populations have been substantially reduced in regions include a minimum of 17,000 farming cowpea households.

Similar scaling field trials have also taken place in Niger, with the virus demonstration at the farmers' level involving 2498+ cowpea's producers in 100+ villages (225+ sites) from 2014-2017, which has allowed the farmers to test (MaviMNPV) + emulsifiable neem oil mixture on around 13,500 m^2. Similar efforts have occurred in Burkina Faso. In Burkina Faso, we have widely assessed several spraying dates with local neem oils in the central part (Pabré village) and southern part (Farako-Ba) of the country in multiple sites per area. This on-farm trial was scaled in two regions, at multiple sites (within those regions) involving a minimum of 50 persons per site.

3.1.5 Studies on the potential for use of biopesticides in the pest control market in Benin (IITA, MSU-Maredia, INRAB, and UIUC)

In Benin, we carried out two follow-up training sessions on the production of the MaviMNPV virus by the women's groups at two localities in Benin (Dassa and Glazoue), with the aim of optimizing the workflow and assuring quality control. The sessions took place July 29 to August 12 in Dassa with 15 participants in total (9 for clean *M. vitrata* production and 6 for the virus production), and July 15 to 27 in Glazoue, with 8 participants (4 each for clean *M. vitrata* production and 6 for the virus production. New 'village rearing labs' were established for this purpose in each of the localities, for separating the virus production from the production of healthy pod borer larvae. A technical staff from the Ministry of Agriculture (in charge of regulatory services and bio-pesticides) actively participated as a resource person throughout the sessions.

In a separate ongoing study, some 120 cowpea value chain actors including producers, market retailers and consumers in the Departments of Couffo, Littoral and Plateau were interviewed about their actual use of pesticides along the value chain. Among the producers, 77% responded they were using chemical pesticides for spraying their cowpea crops, while 23% were using home-made aqueous extracts prepared from neem leaves to protect their fields. Additionally, 65% of the market retailers were using non-chemical approaches to protect their stored cowpea grains, such as hermetic drums, solar drying and PICS bags, while 25% were still using chemical pesticides to protect their cowpea grains in storage. Consumers were largely (98%) aware of pesticide-related issues and were not using any chemicals for their own storage after buying from the market.

3.2 Educational Solutions

As part of our "Educational Solutions" we have developed ICT training materials, online and in-country ICT training sessions available for testing with current partners and potential new partners, FFF program available for testing of impact leading to educational packages for scaling. Potential pathways for deployment of educational videos explored, and we have been testing pathways to deploy videos. We have also continued to explore pass-off of our educational materials to NGOs and government agencies for scaling. Over the past year all of these aforementioned activities have occurred. The INRAN team has used the neem and biocontrol animations in scaling sensitization projects. Through a separate funding stream, UIUC/MSU and IITA have also performed a project testing a diversity of animations (two on health and one on agriculture) in terms of learning gains, as compared to traditional extension approaches. In all three cases, the animations outperformed the traditional extension talks, in terms of learning gains of the participants. Learning gains efforts with farmers in Niger revealed the animations (for biocontrol and neem sprays) were highly effective in transmitting knowledge to farmers. Due to the Scientific Animations Without Borders (SAWBO) program we now have a significant amount of the required educational materials needed for educating farmers on cultural techniques that they can perform to reduce problems with insect attack. We have been and will continue to pass these materials to other groups that can integrate them into their educational programs.

We have ICT training packages and interfaces released to make our materials easily available to outside groups. An ICT training session occurred in Ghana in FY17 and was funded by an outside source with no costs to the Legumes Innovations Lab (funded a grant from QED) (ca. 60 participants), five ICT training sessions have occurred online through Skype with local NGO groups in Ghana (ca. 120 individuals). Over 5000 "Extension Systems in Your Wallet" (over the past three years) have been created and distributed to educators, government officials, and NGOs globally (with many of these going out to groups in the four main countries we work in for our Legumes Innovations Lab program). The "Extension Systems in Your Wallet" is a credit card style USB card that holds SAWBO materials. Users can keep the USB drive in their wallet (save some of their own materials on it) and then share our educational materials with others when and where they see fit. Pass off of these USB cards has continued to occur to country extension programs, FARA, other West African inter-country institutions and many other organizations.

In August 16, 2016, SAWBO and all supporting materials and systems has been legally transferred to Michigan State University. With the move of the SAWBO team to MSU, the system to support the App has been moved and we will be releasing an updated version of the App (1.1.1), with improved functions, in the spring of 2017. We also expect to release a 2.0 version, with more functions available for users, however, this is still in progress. The 1.0, 1.1.1 and 2.0 have all been and will be supported through startup and endowment funds to Dr. Pittendrigh.

This past year a manuscript was published on an experiment performed by the MSU, INRAN and UIUC/MSU team investigating the potential use of these animations in promoting R4D innovations in rural Burkina Faso.

Our team has continued to explore the use of collaborating with and training of NGOs and other groups to perform farmer field flora. Both INERA and INRAN have used these strategies as a way to scale their technologies.

4.1 Capacity building

Our capacity building efforts fall into the following categories: (1) undergraduate and graduate student training, (2) technician training, (3) cross-institutional capacity building for biocontrol agents, and (4) systems to easily pass of our outcomes to other groups that can scale the pest control strategies.

4.1 Undergraduate and Graduate student training

Each of our teams continues to play active role in undergraduate and graduate training programs. The complete list of training efforts is given under degree training.

4.2 Technician Training

As in past years, online cross-training has occurred (via e-mail, Skype and video exchanges based on videos made by IITA) to share skill sets between technical staff at INERA, INRAN, and IITA and to build upon previous exchange programs of technicians. Previous years' training has set the stage for the current status of the project, such that we can now produce and release in larger-scale biological control strategies. Cross-training in this past year revolved around these scaling and deployment strategies.

4.3 Cross-Institutional Capacity Building for Biocontrol Agents

IITA, INERA and INRAN, due to ongoing collaborative efforts are all well-positioned to continue to rear and deploy biocontrol agents on a scale that we expect will significantly impact target pest populations in each of these countries. Additionally, all are also in a position to continue to test, train, and scale the neem plus virus strategy for pest control beyond the scope of this grant. Most importantly, we have evidence that the release of the biocontrol agents in Benin, Niger and Burkina Faso has potential for long-term impact beyond this program and all three countries have significant capacity for future work on biocontrol approaches for both cowpea and other cropping systems.

4.4 Systems to easily pass of our outcomes to other groups that can scale the pest control strategies

Our team has continued to build the necessary sets of networks (e.g., NGOs, companies, FFF organizations, women's organizations, etc.) with whom we can pass off (1) educational materials regarding pest control strategies (through a variety of online and offline systems), (2) neem or neem and virus control strategies, (3) direct deployment of biocontrol agents and (4) FFF training approaches.

IV. Major Achievements

1. Development of bio-control agents useful for scaling for management of cowpea pests.
2. Detailed studies on insect behavior, ecology and biology to maximize the impact of biocontrol agents in the field.
3. Neem and viral spray strategy brought forward into country-wide, large scale field-testing with farmers.
4. Experimental analysis of field data has shown animated educational approach to be as effectively as use of extension agent presentations. This strategy allows us the ability to significantly scale our educational content.
5. SAWBO has been able to demonstrate the potential for other organizations to scale their materials. We have released and tested an App that has the potential to make all of the SAWBO materials highly accessible and the use of the system highly scalable. This will serve at the basis for the development of the 2.0 version that we expect to release before the end of the project.

V. Research Capacity Strengthening

In FY16-17, INERA and INRAN both received capacity building awards. The projects were for refurbishing biocontrol rearing room facilities at INERA and rearing equipment and facilities s at INRAN. All facilities have been refurbished and equipment has been purchased. For example, INERA has rehabilitated the rooms for insects' rearing and purchased equipment allowing them to continuously rear three species of insects: thrips, pod sucking bugs, and *Maruca*. These populations also allow for the continuous maintenance of biocontrol agents for these pests.

VI. Human Resource and Institution Capacity Development

8. Short-Term Training

i. Purpose of Training – Train farmers in IPM
ii. Type of Training - FFF
iii. Country Benefiting – Burkina Faso
iv. Estimated USAID funding for activity
   a. US for Instruction - $2000
   b. N/A
   c. N/A
v. Location and dates of training – Multiple villages in Burkina Faso – July 2017
vi. Number receiving training (by gender) 70 males and 75 females in Burkina Faso
vii. Home institution(s) (if applicable) – INERA
viii. Institution providing training or mechanism - INERA

ix. Purpose of Training – Train farmers in IPM
x. Type of Training - FFF
xi. Country Benefiting –Niger
xii. Estimated USAID funding for activity
   a. US for Instruction - $2000
   b. N/A
   c. N/A
xiii. Location and dates of training – Multiple villages in in Niger near Maradi – July to August 2017
xiv. Number receiving training (by gender) 175 persons including 55 males and 120 females
xv. Home institution(s) (if applicable) –INRAN
xvi. Institution providing training or mechanism - INRAN

Examples of Training Performed by Outside Groups as a Collaboration with INRAN

1) Training in collaboration with MercyCorps NGO working in Maradi and Zinder area and implemented 36 FFS related cowpea production 32 extension agents were trained – Estimated impact of 600 or more farmers with an approximate 50:50 split of women and men.
2) Training in collaboration with the INRAN World bank project on Biopesticide working in Maradi and Zinder area and implemented 68 demonstration fields related to cowpea pest control – Estimated impact of 2000 or more farmers impacted.
3) 600 bio-pesticide neem bags of 250 g were sprayed by 600 cowpea's growers in 60 villages in Niger in 2017.

9. Degree Training

i. Name of trainee: Djibril Aboubakar Souna
ii. Country of Citizenship: Benin
iii. Gender: Male
iv. Host Country Institution Benefiting from Training: IITA
v. Institution providing training:
vi. Supervising CRSP PI: Dr. Manuele Tamò
vii. Degree Program: PhD
viii. Field of Discipline: Entomology
ix. Research Project Title: Bio-ecology of *Therophilus javanus*, a promising biocontrol candidate against *Maruca vitrata*
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 4,000
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds: BMGF, French Embassy
    b. US$ for instruction: 12’000
    c. US$ for participants: 0
    d. US$ for travel: 3000
xii. Start Date: 2014
xiii. Project Completion Date: 2018
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: Partial

i. Name of trainee: Hilaire Kpongbe
ii. Country of Citizenship: Benin
iii. Gender: Male
iv. Host Country Institution Benefiting from Training: IITA
v. Institution providing training: IITA
vi. Supervising CRSP PI: Dr. Manuele Tamò
vii. Degree Program: PhD
viii. Field of Discipline: Entomology
ix. Research Project Title: Population genetics of pod sucking bugs *Clavigralla* spp. and comparison of aggregation pheromone profiles.
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 4,000
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds: ARPPIS
    b. US$ for instruction: 14,000
    c. US$ for participants
    d. US$ for travel: 3,500

xii. Start Date: 2015
xiii. Project Completion Date: 2018
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: Partial

i. Name of trainee: Judith Honfoga
ii. Country of Citizenship: Benin
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: IITA
v. Institution providing training: IITA
vi. Supervising CRSP PI: Dr. Manuele Tamò
vii. Degree Program: MSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Detection and quantification of *Therophilus javaus* parasitism in *Maruca vitrata* larvae using species-specific qPCR primers
x. Estimated USAID funding for activity if not conducted in US
   a. US$ for instruction: 2,000
   b. US$ for participants: 0
   c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
   a. Provider of funds: self
   b. US$ for instruction: 2,000
   c. US$ for participants: 0
   d. US$ for travel: 0
xii. Start Date: 2014
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Completed
xvi. Type of CRSP Support: Partial

i. Name of trainee: Nazyath IMOROU
ii. Country of Citizenship: Benin
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: IITA
v. Institution providing training: IITA
vi. Supervising CRSP PI: Dr. Manuele Tamò
vii. Degree Program: MSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Olfactory responses of T. javanus to frass of M. vitrata.
x. Estimated USAID funding for activity if not conducted in US
   a. US$ for instruction: 2,000
   b. US$ for participants: 0
   c. US$ for travel: 0

xi. Estimated funding from other sources for activity if not conducted in US
  a. Provider of funds: self
  b. US$ for instruction: 2,000
  c. US$ for participants: 0
  d. US$ for travel: 0
xii. Start Date: 2015
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: Partial

i. Name of trainee: Nicolette Montcho
ii. Country of Citizenship: Benin
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: IITA
v. Institution providing training: IITA
vi. Supervising CRSP PI: Dr. Manuele Tamò
vii. Degree Program: MSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Host finding behavior of *Therophilus javanus*, a novel parasitoid of the pod borer *Maruca vitrata*
x. Estimated USAID funding for activity if not conducted in US
  a. US$ for instruction: 2,000
  b. US$ for participants: 0
  c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
  a. Provider of funds: self
  b. US$ for instruction: 2,000
  c. US$ for participants: 0
  d. US$ for travel: 0
xii. Start Date: 2015
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Completed
xvi. Type of CRSP Support: Partial

i. Name of trainee: Sènan Ange Brinette
ii. Country of Citizenship: Benin
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: IITA
v. Institution providing training: IITA
vi. Supervising CRSP PI: Dr. Manuele Tamò
vii. Degree Program: MSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Screening of Benin local isolates of *B. bassiana* against *Maruca vitrata*

x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 2,000
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds: self
    b. US$ for instruction: 2,000
    c. US$ for participants: 0
    d. US$ for travel: 0
xii. Start Date: 2016
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Completed
xvi. Type of CRSP Support: Partial

i. Name of trainee: Enock AZOKPOTA
ii. Country of Citizenship: Benin
iii. Gender: Male
iv. Host Country Institution Benefiting from Training: IITA
v. Institution providing training: IITA
vi. Supervising CRSP PI: Dr. Manuele Tamò
vii. Degree Program: MSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Effect of different sugar sources (honey, sucrose solution, extrafloral nectaries of cowpea varieties, Sesbania, Tehrosia) on fecundity and longevity of *Therophilus javanus and Phanerotoma syleptae* adults
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 2,000
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds: self
    b. US$ for instruction: 2,000
    c. US$ for participants: 0
    d. US$ for travel: 0
xii. Start Date: 2017
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: None

i. Name of trainee: Naasir Abdul NONDICHAO
ii. Country of Citizenship: Benin
iii. Gender: Male
iv. Host Country Institution Benefiting from Training: IITA

v. Institution providing training: IITA
vi. Supervising CRSP PI: Dr. Manuele Tamò
vii. Degree Program: MSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Evaluation of the effects of different dosage formulations and biopesticides combination to control the main pests of cowpea
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 2,000
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds: self
    b. US$ for instruction: 2,000
    c. US$ for participants: 0
    d. US$ for travel: 0
xii. Start Date: 2017
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: None

i. Name of trainee: DRABO Edouard
ii. Country of Citizenship: Burkina Faso
iii. Gender: Male
iv. Host Country Institution Benefiting from Training: INERA
v. Institution providing training: INERA and University Ouagadougou I Pr Joseph KI-ZERBO
vi. Supervising CRSP PI: Dr Fousséni TRAORE
vii. Degree Program: MSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Botanical extract use for cowpea pest management in Sudanian zones at Kamboinse
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 500
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds: self
    b. US$ for instruction: 1000
    c. US$ for participants: 0
    d. US$ for travel: 0
xii. Start Date: 2015
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Completed

xvi. Type of CRSP Support: Partial

i. Name of trainee: Théodore Y. OUEDRAOGO
ii. Country of Citizenship: Burkina Faso
iii. Gender: Male
iv. Host Country Institution Benefiting from Training: INERA
v. Institution providing training: INERA and University Ouagadougou I Pr Joseph KI-ZERBO
vi. Supervising CRSP PI: Dr Fousséni TRAORE
vii. Degree Program: MSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Assessment of neem oil application periods for more efficiency in farmer fields.
x. Estimated USAID funding for activity if not conducted in US
  a. US$ for instruction: 500
  b. US$ for participants: 0
  c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
  a. Provider of funds: self
  b. US$ for instruction: 1000
  c. US$ for participants: 0
  d. US$ for travel: 0
xii. Start Date: 2015
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Completed
xvi. Type of CRSP Support: Partial

i. Name of trainee: Mariam DERA
ii. Country of Citizenship: Burkina Faso
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: INERA
v. Institution providing training: INERA and University Ouagadougou I Pr Joseph KI-ZERBO
vi. Supervising CRSP PI: Dr Clémentine DABIRE
vii. Degree Program: PhD
viii. Field of Discipline: Entomology
ix. Research Project Title: New pests occurring in dry season on cowpea seed production plots.
x. Estimated USAID funding for activity if not conducted in US
  a. US$ for instruction: 1000
  b. US$ for participants: 0
  c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
  a. Provider of funds: self
  b. US$ for instruction: 1500

c. US$ for participants: 0
d. US$ for travel: 0
xii. Start Date: 2014
xiii. Project Completion Date: 2018
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Delayed
xvi. Type of CRSP Support: Partial

i. Name of trainee: Apolline SANON
ii. Country of Citizenship: Burkina Faso
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: INERA
v. Institution providing training: INERA and University Ouagadougou I Pr Joseph KI-ZERBO
vi. Supervising CRSP PI: Dr Clémentine DABIRE
vii. Degree Program: PhD
viii. Field of Discipline: Entomology
ix. Research Project Title: Effectiveness of *Gryon fulviventre* for pod sucking bug biocontrol in cowpea field
x. Estimated USAID funding for activity if not conducted in US
a. US$ for instruction: 1000
b. US$ for participants: 0
c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
a. Provider of funds: self
b. US$ for instruction: 1500
c. US$ for participants: 0
d. US$ for travel: 0
xii. Start Date: 2011
xiii. Project Completion Date: 2015
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Delayed
xvi. Type of CRSP Support: Partial

i. Name of trainee: Bintou Nambe
ii. Country of Citizenship: Burkina Faso
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: Ministry of Agriculture
v. Institution providing training: INERA and CAP/Matourkou
vi. Supervising CRSP PI: Dr Clémentine DABIRE
vii. Degree Program: PhD
viii. Field of Discipline: Entomology
ix. Research Project Title: TBD
x. Estimated USAID funding for activity if not conducted in US
a. US$ for instruction: 1000

b. US$ for participants: 0
c. US$ for travel: 0

xi. Estimated funding from other sources for activity if not conducted in US
a. Provider of funds: self
b. US$ for instruction: 1500
c. US$ for participants: 0
d. US$ for travel: 0

xii. Start Date: 2017
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Discontinued
xvi. Type of CRSP Support: Partial

i. Name of trainee: P. Carine Ouedraogo
ii. Country of Citizenship: Burkina Faso
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: INERA
v. Institution providing training: INERA and University BOBO
vi. Supervising CRSP PI: Dr Clémentine DABIRE
vii. Degree Program: PhD
viii. Field of Discipline: Entomology
ix. Research Project Title: TBD
x. Estimated USAID funding for activity if not conducted in US
a. US$ for instruction: 1000
b. US$ for participants: 0
c. US$ for travel: 0

xi. Estimated funding from other sources for activity if not conducted in US
a. Provider of funds: self
b. US$ for instruction: 1500
c. US$ for participants: 0
d. US$ for travel: 0

xii. Start Date: 2017
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Discontinued
xvi. Type of CRSP Support: Partial

i. Name of trainee: Maimouna Abdourahmane
ii. Country of Citizenship: Niger
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: INRAN
v. Institution providing training: INRAN / University of Maradi
vi. Supervising CRSP PI: Dr. Ibrahim Baoua and Dr. Amadou Laouali
vii. Degree Program: PhD
viii. Field of Discipline: Entomology

ix. Research Project Title: Study on the incidence of *Clavigralla tomentosicollis* on cowpea yield and dissemination of one biopesticide for effective control of the pest in the region of Zinder et Maradi
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 1500
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds: self
    b. US$ for instruction: 1500
    c. US$ for participants: 0
    d. US$ for travel: 0
xii. Start Date: 2014
xiii. Project Completion Date: 2018
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: Partial

i. Name of trainee: Ousseina Abdoulaye
ii. Country of Citizenship: Niger
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: INRAN
v. Institution providing training: INRAN / University of Maradi
vi. Supervising CRSP PI: Dr. Ibrahim Baoua and Dr. Amadou Laouali
vii. Degree Program: PhD
viii. Field of Discipline: Entomology
ix. Research Project Title: Study on the incidence of *Maruca vitrata* on cowpea yield and dissemination of biopesticide (neem seed extract and NPV Mavi virus) for effective control of the pest in the region of Zinder et Maradi
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 1450
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds: self
    b. US$ for instruction: 1500
    c. US$ for participants: 0
    d. US$ for travel: 0
xii. Start Date: 2014
xiii. Project Completion Date: 2018
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: Partial

i. Name of trainee: Rahina Souley Mayaki
ii. Country of Citizenship: Niger
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: INRAN
v. Institution providing training: INRAN / University of Maradi
vi. Supervising CRSP PI: Dr. Ibrahim Baoua and Dr. Amadou Laouali
vii. Degree Program: BSc
viii. Field of Discipline: Entomology
ix. Research Project Title: The effects of Neem grain-based biopesticide on the development of *Clavigralla tomentosicollis* at rural level in the region of Maradi
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 0
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds:
    b. US$ for instruction: 0
    c. US$ for participants: 0
    d. US$ for travel: 0
xii. Start Date: 2012
xiii. Project Completion Date: 2016
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Completed
xvi. Type of CRSP Support: Partial

i. Name of trainee: Soumaila Abdou Issa
ii. Country of Citizenship: Niger
iii. Gender: Male
iv. Host Country Institution Benefiting from Training: INRAN
v. Institution providing training: INRAN / University of Maradi
vi. Supervising CRSP PI: Dr. Ibrahim Baoua and Dr. Amadou Laouali
vii. Degree Program: BSc
viii. Field of Discipline: Entomology
ix. Research Project Title: The effects of Neem grain-based biopesticide on the development of *Clavigralla tomentosicollis* at rural level in the region of Maradi
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 0
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds:
    b. US$ for instruction: 0
    c. US$ for participants: 0
    d. US$ for travel: 0

xii. Start Date: 2012
xiii. Project Completion Date: 2016
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Completed
xvi. Type of CRSP Support: Partial

i. Name of trainee: Nafissatou Illa Boube
ii. Country of Citizenship: Niger
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: INRAN
v. Institution providing training: INRAN / University of Maradi
vi. Supervising CRSP PI: Dr. Ibrahim Baoua and Dr. Amadou Laouali
vii. Degree Program: BSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Study of the population dynamics of *Maruca vitrata* on station
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 0
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds:
    b. US$ for instruction: 0
    c. US$ for participants: 0
    d. US$ for travel: 0
xii. Start Date: 2011
xiii. Project Completion Date: 2016
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Completed
xvi. Type of CRSP Support: Partial

i. Name of trainee: Kader Djibo Amadou
ii. Country of Citizenship: Niger
iii. Gender: Male
iv. Host Country Institution Benefiting from Training: INRAN
v. Institution providing training: INRAN / University of Maradi
vi. Supervising CRSP PI: Dr. Ibrahim Baoua and Dr. Amadou Laouali
vii. Degree Program: BSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Study of the development cycle of *Clavigralla tomentosicollis* in laboratory conditions
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 0
    b. US$ for participants: 0
    c. US$ for travel: 0

xi. Estimated funding from other sources for activity if not conducted in US
  a. Provider of funds:
  b. US$ for instruction: 0
  c. US$ for participants: 0
  d. US$ for travel: 0
xii. Start Date: 2012
xiii. Project Completion Date: 2016
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Completed
xvi. Type of CRSP Support: Partial

i. Name of trainee: Eustache Biaou
ii. Country of Citizenship: Benin
iii. Gender: Male
iv. Host Country Institution Benefiting from Training: INRAB/IITA
v. Institution providing training: INRAB / University of Benin
vi. Supervising CRSP PI: Dr. Adegbola/Dr. Manu Tamo
vii. Degree Program: MSc
viii. Field of Discipline: Social Sciences
ix. Research Project Title: Research Project Title: Biological fight against the devastating of cowpea in Benin: Logic paysannes around the use of bios pesticides in department of Couffo
x. Estimated USAID funding for activity if not conducted in US
  a. US$ for instruction: 0
  b. US$ for participants: 0
  c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
  a. Provider of funds:
  b. US$ for instruction: 0
  c. US$ for participants: 0
  d. US$ for travel: 0
xii. Start Date: 2015
xiii. Project Completion Date: TBD
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: Partial

i. Name of trainee: Deborah Anobil AMOSAH
ii. Country of Citizenship: Ghana
iii. Gender: Female
iv. Host Country Institution Benefiting from Training: CSRI/CRI
v. Institution providing training: Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi
vi. Supervising CRSP PI: Dr. Haruna Braimah
vii. Degree Program: BSc
viii. Field of Discipline: Agriculture

ix. Research Project Title: Neem control strategies on the pests of cowpea in Northern Ghana
x. Estimated USAID funding for activity if not conducted in US
   a. US$ for instruction: 1500
   b. US$ for participants: 0
   c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
   a. Provider of funds: self
   b. US$ for instruction: 500
   c. US$ for participants: 0
   d. US$ for travel: 0
xii. Start Date: 2013
xiii. Project Completion Date: 2016
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: Partial

i. Name of trainee: Samuel Abekah Kwesi
ii. Country of Citizenship: Ghana
iii. Gender: Male
iv. Host Country Institution Benefiting from Training: SARI
v. Institution providing training: University for Development Studies, Tamale, Ghana
vi. Supervising CRSP PI: Dr. Stephen Asante
vii. Degree Program: BSc
viii. Field of Discipline: Entomology
ix. Research Project Title: Evaluation of different storage methods for preserving cowpea grains against *Callosobruchus maculatus Fab.*
x. Estimated USAID funding for activity if not conducted in US
   a. US$ for instruction: 750
   b. US$ for participants: 0
   c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
   a. Provider of funds: self
   b. US$ for instruction: 500
   c. US$ for participants: 0
   d. US$ for travel: 0
xii. Start Date: 2016
xiii. Project Completion Date: 2017
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: Partial

i. Name of trainee: Akosua Addai Asare
ii. Country of Citizenship: Ghana
iii. Gender: Female

iv. Host Country Institution Benefiting from Training: SARI
v. Institution providing training: University for Development Studies, Tamale, Ghana
vi. Supervising CRSP PI: Dr. Stephen Asante and Dr. Braimah
vii. Degree Program: BSc
viii. Field of Discipline: Entomology
ix. Research Project Title:
x. Estimated USAID funding for activity if not conducted in US
    a. US$ for instruction: 750
    b. US$ for participants: 0
    c. US$ for travel: 0
xi. Estimated funding from other sources for activity if not conducted in US
    a. Provider of funds: self
    b. US$ for instruction: 500
    c. US$ for participants: 0
    d. US$ for travel: 0
xii. Start Date: 2015
xiii. Project Completion Date: 2016
xiv. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xv. Training status: Active
xvi. Type of CRSP Support: Partial

VII. Achievement of Gender Equity Goals

Throughout all aspects of our efforts we attempt to meet gender equity goals, from undergraduate, graduate student and technician training to field training of female farmers. In regards to gender issues, we performed a cross-collaborative effort with the Iowa State University team, they have tested (in Mozambique) the learning gains in female farmers (as compared to male farmers), as well as a 2-year later adoption study, and the data supports that the animations were effective in both groups, however, women experienced greater learning gains with the animations than with traditional extension talks. High adoption rates of the given technology were also observed 2-years post-intervention.

VIII. Implementation of Data Management Plan

The data for published cowpea pest studies within the last two years and the associated publications were uploaded to USAID database (https://mft.usaid.gov/courier/web/1000@/wmLogin.html). The name of the data file is **244-10 Genomics Data for Cowpea Pests in Africa**. As of Oct 25, 2017, Kim Marshall from opendata@usaid.gov has confirmed receiving publication files and the readme files associated with each publication. Our team is continuing to make sure any remaining datasets, with host country partners, will be loaded into the system by the end of November 2017.

IX. Scholarly Accomplishments

Theses

Agbaka Fiacre, 2016. Etude des interactions entre *Phanerotma syleptae* et *Therophilus javanus, (*Bhat & Gupa) (Hymenoptera: Braconidae) deux parasitoïdes du lépidoptère *Maruca vitrata* Fabricius (Lepidoptera: Crambidae) ravageur du niébé au laboratoire. FAST/UAC, 38p

Ahongbonon Laurent, 2016. Etude de la table de vie de *Phanerotoma syleptae* (Hymenoptera: Braconidae), parasitoide ovo-larvaire de *Maruca vitrata* (Lepidoptera: Braconidae), ravageur du niébé, *Vigna unguiculata* (L.) Walp.. FAST/UAC, 31p

Alizanon Mesmin, 2016. Etude de la table de *Therophilus javanus* sur milieux naturel et artificiel. FAST/UAC, 36p

Tossou Carmelle, 2016. Test d'efficacité de *Therophilus javanu*s '*(*Bhat & Gupa) (Hymenoptera: Braconidae) sur *Maruca vitrata* (Lepidoptera: Crambidae. FAST/UAC, 36p

Selected Presentations

Tamò, M., E. Dannon, B. Datinon, C. Dabiré, F Traoré, B. Pittendrigh, and R. Srinivasan. 2017. Science-driven pest management saves cowpea farms from insect pests. Lead paper. The Feed the Future Legume Innovation Lab, Grain Legume Research Conference, Ouagadougou, Burkina Faso, August 13 to 18.

Pittendrigh, B., C. Dabire-Binso, I. Baoua, F. Traore, A. Laouali, S. Asante, H. Braimah, M. Mochaih, B. Datinon, E. Biaou, J. Bello-Bravo, and M. Tamò. 2017. Integrated Pest Management (IPM) in cowpea cropping systems in West Africa: From genomics to biocontrol agents, biopesticides, and extension. Invited paper. The Feed the Future Legume Innovation Lab, Grain Legume Research Conference, Ouagadougou, Burkina Faso, August 13 to 18.

Zakari, O., A., I. Baoua, S. Boureima, L. Amadou, M. Tamò, S. Mahamane S, and B. R. Pittendrigh. 2017. Biopesticide test of neem seed (*Azadirachta indica* A. Juss.) extract and MaviNPV Virus for the control of main insect pests of cowpea (*Vigna unguiculata* L. Walp.) in Niger. The Feed the Future Legume Innovation Lab, Grain Legume Research Conference, Ouagadougou, Burkina Faso, August 13 to 18.

Abdourahmane, M., I. Baoua, L. Amadou, S. Mahamane, M. Tamò, and B. R. Pittendrigh. 2017. Farmer field test of neem-based (*Azadirachta indica*) and entomopathogenic MaviNPV virus formulations on the main insect pests of cowpea in Niger. The Feed the Future Legume Innovation Lab, Grain Legume Research Conference, Ouagadougou, Burkina Faso, August 13 to 18.

Bello-Bravo, J., E. A. Dannon, O. A. Zakari, A. Laouali, I. Baoua, M. Tamò, and B. R. Pittendrigh. 2017. An assessment of localized animated educational videos (LAV) versus traditional extension presentations or LAV followed by extension agent discussions among farmers in Benin and Niger. The Feed the Future Legume Innovation Lab, Grain Legume Research Conference, Ouagadougou, Burkina Faso, August 13 to 18.

Posters

Abdourahmane, M., I. Baoua, L. Amadou., M. Tamò, B. R. Pittendrigh, and S. Mahamane. 2017. Life Cycle of *Clavigralla tomentosicollis* (Stal.) and its Impact on Crop Yields of Cowpea (*Vigna unguiculata* L. Walp.) in Niger. The Feed the Future Legume Innovation Lab, Grain Legume Research Conference, Ouagadougou, Burkina Faso, August 13 to 18.

Toffa Mehinto, J., E. Dannon, O. Kobi, D. Kpindou, and M. Tamò. 2017. Comparative efficacy of Biopesticides for Controlling the Legume Pod Borer, *Maruca Vitrata* Fabricius (Lepidoptera: Crambidae) Under Field Conditions in Benin. The Feed the Future Legume Innovation Lab, Grain Legume Research Conference, Ouagadougou, Burkina Faso, August 13 to 18.

Agyekum, M., C. Donovan, M. Tamò, B. Pittendrigh, and E. Biaou. 2017. Precision Pest Management Technology Delivers Financial and Health Benefits for Farmers in West Africa. The Feed the Future Legume Innovation Lab, Grain Legume Research Conference, Ouagadougou, Burkina Faso, August 13 to 18.

Publications

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X. Achievement of Impact Pathway Action Plan

Objective 1

In terms of "Program Logic" we have completed all steps (up to and including Step 4.5) for this section. We feel that we were able to achieve all goals set forth at the beginning of the project and this impact pathway action plan document was an important for us to keep track of where we stood regarding our goals, as they were originally outlined.

Objective 2

In terms of "Program Logic" we have completed all steps (up to and including Step 4.5) for this section.

Objective 3

In terms of "Program Logic" we have completed all steps (up to and including Step 4.5) for this section.

ANNEXES

Annex 1. Tables, Figures, and Photos Cited in the Report

N/A

Annex 2. Literature Cited

N/A

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes

Report on the Achievement of "Milestones of Progress"

(For the Period: Oct 1, 2016 – March 31, 2017)

This form should be completed by the U.S. Lead PI and submitted to the MO by April 1, 2017

Project Title: #REF!

	Abbreviated name of institutions																							
	#REF!			#REF!			#REF!			#REF!			#REF!			#REF!			#REF!			UIUC		
	Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved	
Milestones by Objectives	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*	4/1/17	Y	N*
	(Tick mark the Yes or No column for identified milestones by institution)																							
Objective 1: Define the pest problems																								
1.1 Insect scouting				#REF!	X		#REF!	X		#REF!	X					#REF!	X		#REF!	X				
1.2 Molecular analysis	#REF!	X																						
1.3 Travel to West Africa to finalize analysis of IPM strategies																								
Objective 2: Appropriate solutions																								
2.1 Biocontrol agent lab studies				#REF!	X																			
2.2Thrip parasitoid				#REF!	X		#REF!	X		#REF!	X					#REF!	X		#REF!	X				
2.3Egg parasitoid				#REF!	X																			
2.4 Bio-pesticide production				#REF!	X																			
2.5 Resistant/tolerant varieties							#REF!	X		#REF!	X													
Objective 3: Scaling of solutions																								
3.1 Inoculative release of natural enemies				#REF!	X		#REF!	X		#REF!	X					#REF!		X	#REF!		X			
3.2 Development&Investigations of Educational sol	#REF!	X																						
3.3 Involving private sector and NGO	#REF!	X		#REF!	X		#REF!	X		#REF!	X					#REF!	X		#REF!	X				
3.4 Understanding the potential for scaling	#REF!	X		#REF!	X		#REF!	X		#REF!	X		#REF!	X										
Objective 4: Capacity Training																								
4.1 Student training	#REF!	X		#REF!	X		#REF!	X		#REF!	X		#REF!	X		#REF!	X		#REF!	X				
4.2 ICT training tools	#REF!	X		#REF!	X		X	X		#REF!	X													
4.3 Technicican training				#REF!	X		#REF!	X		#REF!	X													
4.4 ICT training	X	X																						
4.5 Farmer Field Flora/Farmer Training/Training of trainers																								
Name of the PI reporting on milestones by institution	Barry Robert Pittendrigh			Manuele Tamò			Clementine Dabire			Laouali Amadou/Baoua Ibrahim			Eustache Biaou			Moses Mochaih			Stephen Asante			Kenneth Paige		

Signature/Initials:

Name of the U.S. Lead PI submitting this report to the MO Barry Robert Pittendrigh

Signature

4/1/2017 **Date**

4/1/2017 **Date**

* *Please provide an explanation for not achieving the milestones on a separate sheet.*

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes
Report on the Achievement of "Milestones of Progress"
(For the Period: April 1, 2017 -- Sept 30, 2017)

This form should be completed by the U.S. Lead PI and submitted to the MO November 13, 2017

Project Title: #REF!

	Abbreviated name of institutions																							
	MSU			#REF!			#REF!			#REF!			#REF!			#REF!			#REF!			UIUC		
	Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved	
Milestones by Objectives	9/30/17	Y	N*	9/30/17	Y	N*	9/30/17	Y	N*	9/30/17	Y	N*	9/30/17	Y	N*	9/30/17	Y	N*	9/30/17	Y	N*	9/30/17	Y	N*
	(Tick mark the Yes or No column for identified milestones by institution)																							
Objective 1: Define the pest problems																								
1.1 Insect scouting				#REF!	X		#REF!	X		#REF!	X					#REF!	X		#REF!	X				
1.2 Molecular analysis	#REF!	X																						
1.3 Travel to West Africa to finalize analysis of IPM strategies																						X	X	
Objective 2: Appropriate solutions																								
2.1 Biocontrol agent lab studies				#REF!	X																			
2.2Thrip parasitoid				#REF!	X		#REF!	X		#REF!	X					#REF!	X		#REF!	X				
2.3Egg parasitoid				#REF!	X																			
2.4 Bio-pesticide production				#REF!	X																			
2.5 Resistant/tolerant varieties							#REF!	X		#REF!	X													
Objective 3: Scaling of solutions																								
3.1 Inoculative release of natural enemies				#REF!	X		#REF!	X		#REF!	X					#REF!	X		#REF!	X				
3.2 Development&Investigations of Educational sol	#REF!	X																						
3.3 Involving private sector and NGO	#REF!	X		#REF!	X		#REF!	X		#REF!	X					#REF!	X		#REF!	X				
3.4 Understanding the potential for scaling	#REF!	X		#REF!	X		#REF!	X		#REF!	X		#REF!	X										
Objective 4: Capacity Training																								
4.1 Student training	#REF!	X		#REF!	X		#REF!	X		#REF!	X		#REF!	X		#REF!	X		#REF!	X				
4.2 ICT training tools	#REF!	X		#REF!	X		X	X		#REF!	X													
4.3 Technician training				#REF!	X		#REF!	X		#REF!	X													
4.4 ICT training	X	X																						
4.5 Farmer Field Flora/Farmer Training/Training of trainers							X	X		X	X													

Name of the PI reporting on milestones by institution	Barry Robert Pittendrigh	Manuele Tamò	Fousseni Traore	Laouali Amadou/Baoua Ibrahim	Eustache Biaou	Moses Mochaih	Stephen Asante	Kenneth Paige
Signature/Initials:								

Name of the U.S. Lead PI submitting this report to the MO Barry Robert Pittendrigh

Signature

Date

Date

* *Please provide an explanation for not achieving the milestones on a separate sheet.*

IX. Farmer Decision Making Strategies for Improved Soil Fertility Management in Maize-Bean Production Systems (SO2.1)

Lead U.S. Principal Investigator and University:
Robert Mazur - Iowa State University

Collaborating Host Country and U.S. PIs and Institutions:
Moses Tenywa - Makerere University, Uganda
Richard Miiro - Makerere University, Uganda
Onesmus Semalulu - Soils & Agro-meteorology, National Agricultural Research Lab, Uganda
Ricardo Maria - Institute of Agriculture Research of Mozambique
Sostino Mocumbe - Institute of Agriculture Research of Mozambique
Eric Abbott - Iowa State University
Andrew Lenssen - Iowa State University
Ebby Luvaga - Iowa State University
Bradley Miller - Iowa State University
Lee Burras - Iowa State University
Russell Yost - University of Hawai`i at Manoa
Julia Bello-Bravo - Michigan State University
Barry Pittendrigh - Michigan State University

I. Abstract of Research and Capacity Strengthening Achievements

Following completion of research experiments on common bean in Uganda, five rainy seasons of community-based field trials enabled farmers to learn about and evaluate improved management practices and technologies for adoption. A multistakeholder bean Innovation Platform continues to develop in membership size, diversity, enthusiasm and capability, with 10 value chain member organizations and 1000+ farmers. In Mozambique, field experiments were completed mid-2017 by IIAM. Two SAWBO video animations were released on research-based farmer-validated bean production recommendations in Uganda and Mozambique and one on jerry can storage for Mozambique. IIAM created and is field testing its first App, focused on bean production recommendations. Project team members presented 14 papers/posters at the Grain Legume Research Conference in Burkina Faso. One M.S. student graduated and two are near completion. One M.S. student and one Ph.D. student are progressing well. Research results are published in peer-reviewed journal articles and a book chapter, with others being prepared. Some will be disseminated in regional/national practitioner and policy outlets in Africa. Training methods and media are ready for dissemination to intermediate and end users. Capacity strengthening through applied research-based training has been successfully conducted.

II. Project Problem Statement and Justification

Sustainable intensification of smallholder cropping systems requires improved soil fertility management in which legumes play an integral role, with enhanced capabilities among farmers to diagnose and identify solutions to important soil and other production constraints. Project research activities focus on predominant soil types in key common bean production regions in Masaka and Rakai districts south-central Uganda and Gurúè district, northern Mozambique. To understand potentially limiting soil characteristics and nutrient deficiencies, relevant analyses include soil physical and chemical properties, nutrient omission studies, and researcher-managed field experiments. It is also valuable that researchers understand local/indigenous criteria and systems for characterizing soils, particularly those reflecting fertility vs. deficiencies and crops that are appropriate. The combination of scientific and local criteria can enhance understanding and sustainable implementation of recommended cropping system improvements.

Based on results of field experiments, community-based trials and demonstration sites engage farmers in understanding key management practices and technologies (MPT) recommended by researchers. Farmer field days stimulate interest through direct observation, participation, and comparison of site-specific MPT. These activities engage producers and other stakeholders in social learning, stimulate interest in the demonstrations and trials, and foster widespread use of MPT that are proven successful under local conditions. The MPT include field preparation and measurement, seed selection, plant spacing, application of organic and inorganic fertilizers, weeding, post-harvest handling, and farm business economic analysis.

An innovative communication and dissemination strategy integrates the use of multimedia, including radio, video animations delivered via smartphones, and print materials delivered through networks of partner organizations supplemented by field demonstrations and other participatory activities. These engage farmers with diverse backgrounds and characteristics and other key stakeholders in widespread dissemination and adoption of improved management practices and technologies to improve soil fertility and increase bean productivity.

III. Technical Research Progress

<u>Objective 1</u>: Characterize Smallholder Farmers' Motivations, Knowledge and Practices

Smallholder farmers continued their learning through initiating on-farm trials (12 one-acre sites in Masaka and 10 one-acre sides in Rakai) and leading farmer field days associated with those field trials. During the pre-season period, learning was fostered through discussions and decision making pertaining to location of on-farm trials and types and levels of treatments and inputs to be used. Farmers generally meet monthly for co-learning. Experiential learning during implementation of on-farm trials occurred when applying treatments, hands-on husbandry practices, observation of bean performance, and peer-to-peer communication. Smallholder farmers also learned through assessment of the results of on-farm trials at community level during informal field visits by both group members and passersby and organized field days that systematically explain the management practices and technologies involved, the costs incurred, and yields obtained. Local social networks have also been a channel for social learning and encouraging non-member farmers to learn. Finally, learning takes place during Innovation Platform meetings when they plan for the subsequent season's activities. Six joint IP meetings have been held from October 2016 to September 2017, with an average of 50 participants each.

Objective 2: Develop and Refine Models of Smallholder Bean Farmers' Decision Making

Farmers' Learning and Adoption

After identifying the resources and actions required for increasing bean crop productivity and marketing, and improving soil fertility, it was important to document farmers' actions to invest in and adopt (or intentions to do so) new management practices and technologies. Understanding the significance of these actions involved interviews with farmers and leaders of the multi-stakeholder innovation platform regarding the latter's efforts and successes. Information gained during these interviews provided the basis for formulation of recommendations for training and support to increase bean crop productivity and marketing, and to improve soil fertility.

Project farmers who have been part of the Innovation Platform in Masaka and Rakai Districts, have hosted field trails, demonstration gardens and field days. Through these activities, they have learned to mobilize and manage key resources: money to buy improved bean seed, including drought resistant varieties; mineral fertilizers (diammonium phosphate - DAP and urea), organic chicken manure, and biochar; pesticides; and labor hired for weeding, harvesting, etc. Some have purchased surfactants that reduce moisture loss and allow the crop to withstand drought, and some have invested in irrigation.

Focus Group Discussions were conducted with farmers in Masaka and Rakai during May 2017 by Rob Mazur and Naboth Bwambale. They met with farmers who are members of the Bean Innovation Platform to explore three topics: (1) growing beans, (2) soil fertility, and (3) being part of the bean innovation platform. Focus groups consisted of 4-8 participants, women and men, and lasted approximately two hours. For each topic, *four* questions guided the discussion:

- What are the *most important* things that you've *learned*? from whom?
- What *changes* have you made in relation to that *after learning in this project*?
- What *additional things* would you *like to learn*?
- What would be the *best way* to *help you learn*?

Key findings and insights from the focus group discussions are highlighted in this and other sections of this report. Of particular importance here is that farmers deeply appreciate the full range of benefits associated with recommended bean crop MPT. They described those MPT in detail regarding the MPT and procedures to use them: soil testing; early field preparation; timely planting in rows with proper spacing; trying new seed varieties and using new, quality seed at least every other season; applying manure and/or fertilizer according to soil type in a banded manner; monocropping beans when focusing on food security and marketing; and hermetic post-harvest storage of bean seed.

Interviews were conducted with 104 farmers in Masaka and Rakai districts of Uganda by a team led by Eric Abbott. The interviews were intended to assess farmers' learning when shown either a video animation produced by SAWBO containing the project's research-developed and farmer-tested bean recommendations or a similar color print version using still images from the video animation plus text. Both were in Luganda, the local language. Following seeing and hearing - or reading - the recommendations, farmers were tested on what they remembered, what practices they already follow, and what practices they plan to follow in the next harvest season. Many of these farmers were members of the Innovation Platform or the Community Enterprise Development Organisation (CEDO) seed production NGO and already knew about some of the practices, but none had seen the video or print materials before. Results of this learning are discussed below in the section for Objective 4.

Taking together those who indicated that they are either already doing it or say that they will do it, it is clear that most farmers will be following these guidelines in the next season. Examples of those who will not include 14% who won't plant in lines, generally because they consider that it involves too much work. Between 15-21% say they won't use at least one type of fertilizer, usually because they don't have access to it or don't have the money. Overall, however, the great majority of those who don't currently do it say they will do it in the next season.

- *TABLE 1* -

Table 1: shows farmers' adoption, plans and perspectives on management practices and technologies, Masaka and Rakai, Uganda in May 2017

<u>Value of Innovation Platform Participation</u>

During the focus group discussions, many farmers conveyed their understanding, gained through project activities, that fertility of any type of soil can and should be improved ("we must feed the soil"), since their soils are 'exhausted' and current conditions and improvement are associated with their management practices. Farmers recognize that "we can transform poor soils into productive ones." Applying fertilizer and manure according to soil type is viewed as beneficial not only to beans but also will carry over to the subsequent crop on that field. Several are now utilizing soil and water conservation measures.

On-site soil testing that provides quick results and is accompanied by guidelines which specify the quantities of fertilizer to add is of great interest to farmers, as conveyed clearly during the focus group discussions. Farmer group members are prepared to buy soil test kits on credit and share soil test results with group members and neighbors.

During focus group discussions, farmers expressed their appreciation for the increased access to knowledge, services and inputs derived from interacting with an array of value chain stakeholders who form the multistakeholder bean innovation platform, as well as knowledge from fellow bean farmers' experiences and suggestions. They have experienced a 'mindset shift' which reflects planning for the full crop cycle, developed a business orientation ("my garden is my office"), searched for new information and "all ways of learning", educated/trained others in improved bean crop management practices, and conveyed pride in their transformative achievements: "I am proud to be well informed and knowledgeable, no longer dependent on others to decide." "I have advanced from being a grain and seed buyer to now being a grain and seed seller." "I have seen the light – I will never stop growing beans!"

Farmers described how active participation and interaction in the innovation platform facilitates experiential collective learning and core knowledge development of all members. Members develop horizontal and vertical social linkages and networks which help them to identify 'true' partners needed to increase production and to 'know the market' and coordinate joint decision making and action.

Farmers have already experienced improved household food security, mobilized collectively for loans to increase productivity and production, increased savings, opened bank accounts, purchased durable goods, and used profits from coffee to invest in more intensive and expanded bean production.

Production Economics and Marketing

During the focus group discussions, it became clear that improved systems of record keeping are of great interest for farmers who want to calculate their costs and assess profitability in relation to market prices. They also want to better understand the range of market prices and details of contract farming, and thereby negotiate more favorable terms.

Beans are often intercropped – primarily with maize, but also with a variety of other crops. Researcher data and farmer generated information from our study allowed farmers to understand the production costs associated with various cropping systems so that they are able to make informed decisions. Analysis of primary data collected in Rakai and Masaka from 2014-2017 (during both growing seasons each year) on input and labor costs, and on bean sale prices, revealed the unreliability of data from a single source. Results of our profitability analyses varied significantly by sources of cost and price information. It was also evident that some farmers may have intrinsic motives for providing less-than-accurate information to researchers (cultural norms, privacy concerns, inflated rental price charged for research plots, etc.). This guided the development of an instrument that allows farmers to play a central role in data collection.

Our research documented that farmers selling beans are not only price takers, but also sell most of their beans individually at the farm gate. Nearly all farmers sold their beans individually – 90% in Uganda and 98% in Mozambique. It was evident that the average farmer is not well equipped to determine a profitable or even breakeven price when selling beans. Traders have played a major role as sources of information for farm inputs and production costs, as well as bean prices. This type of information asymmetry negatively impacted farmer profits. To enable farmers to better understand bean marketing practices, our research focused on methods of price discovery and determination that involve farmers documenting their production costs. Increased access to knowledge on accurate documentation of market bean prices, costs of land, inputs and labor, as well as yield data are not only key to planning for future seasons, but also help determine an individual breakeven price for that season, and ultimately use it as a benchmark for an asking sell price for their beans.

We undertook three iterations to aid farmers in keeping track of their production costs so that they are able to use the information generated to determine a breakeven price for their beans.

- Iteration #1: We designed a simple one page form for farmers to keep track of the most basic production costs (land preparation, seed, fertilizer, planting, weeding, harvesting, etc.) to spur interest in the decision making process.
- Iteration #2: Included all items in itineration #1 plus additional farmer profile information in a ringed bound booklet.
- Iteration #3: Included iterations #1 and #2, plus using a mobile phone App among members of farmers' networks.

Iterations #1 and #2 have been successfully implemented with promising results, while #3 is still in progress. It is designed to provide farmers with more advanced tools and a platform through which they are able to participate in discovering and sharing not only bean price data but also pest outbreaks and other farm related challenges and opportunities.

Results from community-based field trials revealed that it is profitable for farmers to invest in fertilizer (organic, inorganic, and combinations) to increase bean yields. Having relevant and accurate data on market prices and input costs is vital for smallholder farmers to realize profitability from bean production. As Bluetooth-capable mobile phones and smartphones become increasingly prevalent, farmers will be able to more easily capture information about their soils, climatic conditions, weeds, and pests, in addition to the cost and price data. Using the basic mobile phone App that we are developing, farmers will be part of a comprehensive network that can gather and share relevant farming data and information for improved soil fertility and increased bean productivity.

Objective 3: Develop and Validate Diagnostic and Decision Support Aids

Solutions to Soil Fertility and Related Bean Production Constraints

The project research team determined solutions to soil fertility and other bean production constraints. For the research region in Uganda, these are listed here:

- Seeding for a density of 20 plants m^{-2} improves common bean yield over the standard farmer practice of planting bean for a stand density of 10 plants m^{-2}.
- Planting common bean in rows on 50-cm centers improves yield over the standard farmer practice of scatter planting through improved water use efficiency.
- Planting common bean in rows improves efficiency of weeding, allowing farmers to more completely remove weeds with far less labor utilized.
- For red soil, apply per acre: DAP 30 kg, urea 1.2 kg, 1000 kg of chicken manure
- For gravelly soil, apply per acre: DAP 30 kg, urea 1.5 kg, 1000 kg of chicken manure

- For black soil, apply per acre: DAP 15kg/acre, urea 0.75 kg, 1000 kg of chicken manure
- Utilization of 100-200 kg ha^{-1} of agricultural limestone on black soil can provide Ca and Mg for common bean, two nutrients often inadequate on the better soils in the region.
- Utilization of agricultural limestone at 1 to 2 Mt ha^{-1} for Ca and Mg and alleviation of aluminum toxicity, potash for K, and planting in 50-cm rows with 10-cm between seed of improved bean varieties, can increase yield of common bean 200% on red Oxisol (Ferralsol) soil. However, due to the high price of agricultural limestone, these systems are not currently profitable for smallholder farmers.
- Intensive input systems of common bean production can be profitable on black Mollisol (Phaeozem) soils. These intensive systems include utilization of 100 to 200 kg ha^{-1} agricultural limestone to supply Ca and Mg, potash for K, and planting in 50-cm rows with 10-cm between seed of improved bean varieties, can double yield of common bean and be economically profitable for smallholder farmers.
- Weeding common bean at two weeks after emergence, weeding a second time two to three weeks later, and removal of weeds above the bean canopy an additional two weeks later can improve bean yield. When beans are planted in rows, this weed management system requires substantially less time and labor than when beans are scatter-planted.
- Planting varieties of common bean with improved resistance to multiple diseases is essential regardless of management system used. Use of older varieties of beans results in less yield whenever and wherever stress occurs from limited or excess soil water. Older varieties have limited or no resistance to common disease-causing pathogens and should not be planted because the National Crops Resources Research Institute has released numerous varieties with improved resistance and suitable cooking times and taste.
- Nutrients/inputs (lime, P) for which the prices are currently prohibitive for the smallholder farmers can be incrementally added per season with beneficial effect.

During the past two years, two related field experiments were conducted in Gurúè, Mozambique using locally available Evate rock phosphate (ERP), limestone, common bean, and pigeon pea (*Cajanus cajan* L.). Research sites included the acidic reddish-brown soils at summit and backslope topographic positions in Mepuagíua. The goal of the first experiment was to improve soil conditions through incorporation of limestone to ameliorate low pH and aluminum toxicity. For common bean, soil pH was adjusted upward using lime produced in nearby Nampula Province at rates of 0, 1.0, 3.0, and 6.0 Mg ha^{-1}. In this study, seedling emergence and early growth of common bean was extremely poor in the absence of lime application. Maximum growth occurred with the modest application of 1.0 Mg ha^{-1} of lime. Additional studies are needed to determine the number of growing seasons that the 1.0 Mg ha^{-1} of lime will continue to support improved common bean growth. The second experiment utilized pigeon pea, which is better suited than common bean for the local soil conditions, particularly the low pH. This experiment compared two sources of phosphorus, the local ERP (40.7% P_2O_5) and triple super phosphate (TSP) (45% P_2O_5), each at four P application rates. The ERP was applied at rates of 20, 40, 80 and 160 kg P ha^{-1} while the TSP was applied at 0, 10, 20 and 40 kg P ha^{-1}. Grain yield of pigeon pea attained 1000 kg grain ha^{-1} following the application of 80 kg P ha^{-1} from ERP. By comparison, 20 kg P ha^{-1} as TSP was needed to reach the maximum yield of pigeon pea grain. This ratio suggests that Evate rock phosphate was 25% as effective as TSP on a total P basis. This research suggests that ERP can be an effective amendment for increased food grain productivity on the acid, relatively infertile upland soils of central Mozambique.

Using Improved Maps of Local Soil Types in Uganda to Guide Soil Fertility Decision Making

Objectives for this portion of the project were to (a) learn the local soil names while building trust with the farmers, (b) understand the soil-landscape relationships of those soils, (c) measure the properties of those soils, and (d) produce a set of visual aids. To be successful, the visual aids need to bridge local knowledge with the results of fieldwork and expertise in soil fertility. After the research was completed, officials provided and discussed soil reports consisting of (a) maps on aerial imagery that use local soil names, (b) block diagrams showing local landscape-soil relationships, (c) tables of suitabilities and recommended practices for each local soil, and (d) tables with fertilizer and lime recommendations for the important crops based upon locally measured soil properties.

Methods

1. *Initial Engagement of Local Farmers (6 hours at village)* - in the creation of an indigenous soil map for their village. It facilitates trust, interest, and commitment by all participants (research scientists, extension specialists, farmers, etc.). It provides the scientific community with knowledge about local needs and wants. It provides the scientific community with the appropriate soil names that insure subsequent soil maps and recommendations resonate with the farmers. It sensitizes all participants to the local soil and field conditions. This engagement can be quite short – e.g., 1 day of meetings and collective mapping of the village.
2. *Inclusion of Soil Sampling (6 hours).* We found that simple, quick analyses such as slope steepness, color-book color, and litmus paper pH were especially valuable. Doing these has three impacts. First, it allows the scientists to have some semi-quantitative data that permit comparisons with the literature and other villages as well as providing a basis for final recommendations. Second, the soil measurements – especially pH - helps the farmers. Third, it furthers trust and interest in the project by all participants. Refinement will be needed to determine if the soil sampling impact is greatest if it occurs during the original indigenous map creation or if it is done subsequently. The key is to get the data back to the farmers quickly and to put it in terms of their soil names.
3. *Soil Mapping, Leveraging Modern Geospatial Tools (8 hours).* These maps blend catenic/hillslope principles with the original indigenous soil map. The two most important features of this map are (a) overlaying the soil map units on detailed satellite imagery so local farmers can orient themselves using local features such as roads, homesteads and such, and (b) use of local soil names. (8 hours - best if there is access to GIS).

4. *Creation of a Block Diagram* illustrating soil-landscape relationships (2 hours drawing).
5. *Summarizing the properties* of each of the local soils (as measured) as well as soil properties from comparable locations in well-organized tables (6 hours data analysis and writing).
6. *Creation of Management Guides* (4 hours writing) including tables with:
   a. *suitabilities* for various cropping systems
   b. *risks* of soil erosion, soil organic matter loss, etc.
   c. *fertilizer and lime recommendations*.
7. *Synthesis of a Final Report* with all of the above, followed by printing same (6 hours).
8. *Follow-Up Village Meeting* to present and discuss the preceding with farmers (6 hours).

- *TABLE 2* -

Table 2: shows selected soil properties for the surface horizon (0 to 15 cm) at releve sites on 16 model farms in Masaka and Rakai Districts, Uganda, 2014

- *TABLE 3* -

Table 3: shows suitability recommendations for bean production in Masaka and Rakai, Uganda

Results

A village-specific map, showing local soil variation, overlaid on satellite imagery with local landmarks combined with a block diagram helps farmers connect to the information and understand the spatial relationships of the soil landscape in which they live. That information has implications for:

- *Soil and Water Conservation* - Maps of local soil types coupled with a block diagram introducing the aspects of slope steepness and location on the landscape can be powerful tools for communicating how soil loss occurs and promoting adoption of soil and water conservation measures.
- *Fertility Management Decisions* - Maps of local soil types can be used by farmers to improve their farm level decisions on soil fertility management. Farmers are already making amendments on their soils but use of the maps helps in refining their decisions.
- *Soil Testing* - The process of soil testing for farmers is strengthened and the utility multiplied by availability of local soil maps.

- *Community Cooperation* - A village map of local soils helps in building collective action for soil conservation and fertility management.

- FIGURE 1 –

Figure 1. Elevation data from the Shuttle Radar Topography Mission (SRTM) was re-interpolated to produce a high resolution base map of slope gradient. There was insufficient data available to create a statistical model, but fieldwork provided the basis for a mental model relating soil type with slope gradient and relative slope position. Guided by both the slope gradient map and the soil observations, a detailed map of soil units based on soil-landscape relationships was produced.

- FIGURE 2 -

Figure 2. This map was presented to the farmers, showing the partnership between the contributing institutions. The soil map was draped over satellite imagery to help the farmers orient themselves on the map with landscape features with which they were already familiar. Many farmers were surprised by the extent of red soils in their village.

- FIGURE 3 -

Figure 3. To assist in the communication of the soil-landscape relationship concepts, this block diagram was developed. It demonstrated the expected repeating pattern of soils in the area, known as a catena. The pattern of red and black soils illustrated why certain areas have black soils. Understanding how the black soil is lost and accumulated in different parts of the hillslope motivated the farmers to improve soil conservation practices that can improve their soil fertility.

Implementation of Soil Mapping in Masaka

- Fieldwork and spatial analysis to provide the framework for soil map development at two locations
- Grid sampling of villages to identify soil-landscape relationships
- Soil description by local farmers for producing a map legend suitable for local understanding.

Presentation and Utilization of Soil Maps by Farmers in Masaka

- Maps communicating how soil loss occurs and promoting adoption of soil and water conservation measures
- Process of soil testing for farmers strengthened and the utility multiplied by availability of local soil maps
- A village map of local soils helps in building collective action for soil conservation and fertility management
- Soil survey interpretations on nutrient management

- Farmers have refined their soil conservation practices to include water diversions consistent with the soil map and landscape
- Farmers have soil fertility-soil liming-soil maps recommendations.

Farmers' participation in diagnosing their soil-related problems using maps (which combine indigenous knowledge with scientific knowledge) and predict local soil types, as well as block diagrams, helped them understand and appreciate new dimensions of the problem as never before, changing their mind-sets and attitudes. In addition, when we first inquired about indigenous knowledge regarding soils, it was largely tacit. However, after working with farmers and extension workers we were able to improve the local soil classification system and make it hierarchical.

Farmers were then able to put in practice the soil erosion control measures that they had never previously implemented. Moreover, discussions with extension workers revealed that they were only somewhat aware of farmers' indigenous knowledge about their soils, but did not really appreciate its value. Upon learning the findings of the research project, they have now been empowered to support farmers both with and without access to soil testing services using the improved maps of local soil types in conjunction with guidelines indicating the amendments for each local soil type. Both extension workers and farmers used the maps and indicated that they were useful, and even provided suggestions for scaling up the knowledge gained in combining indigenous knowledge with scientific knowledge beyond our study site.

Way Forward

The experience of this soil mapping project in the villages of Kiwanyizi and Kaganda, Uganda demonstrated that this process builds on existing local knowledge and provides farmers with the tools to expand their thinking about the functioning of their soil landscape. Improved soil maps can be produced remotely, but are much more accurate when supported by local soil data. Further, the key to the soil map having maximum impact is the involvement of the farmers. The 8-step process implemented in this soil mapping project is scalable and has the capability of building upon each preceding village's soil map by increasing the data support for map unit descriptions and refining soil-landscape concepts. There is a tremendous opportunity to see the results from this project replicated across the region.

Objective 4: Develop and Assess Effectiveness of Innovative Approaches for Dissemination

The lack of effective channels for delivering quality information about legume production to farmers and for gathering feedback for researchers and policymakers constitutes a serious constraint to enhancing bean production and improving soil quality in both Uganda and Mozambique. Researchers are identifying and testing innovative methods for making farmers aware of project-based recommendations to improve their soils and increase bean productivity, and ways that farmers can actively become involved in the process so that their knowledge and insights are integrated into project-based recommendations. Highlights of progress made during the 2016-2017 period include:

Development, Pre-Testing and Release of Research-Based, Farmer-Validated Bean Production Recommendations Using a Variety of Channels and Methods

Uganda:

- Use of an Innovation Platform and its associated groups and NGOs to prioritize needs, participate in research design, and conduct farmer-managed field trials to validate key recommendations for improving bean production, including: use of improved seed; specific fertilizer recommendations for black, stony and red soils using chicken manure, DAP and urea; banding fertilizer application; planting in rows and according to spacing recommendations; and conducting three weedings.
- Conducting a radio 'launch event' to bring together local officials, extension, IP representatives, input providers and farmers to demonstrate effectiveness of bean recommendations, show soil testing techniques and improved seed varieties. This consisted of a one-hour live radio program using the local station most-listened to for agricultural information in Masaka and Rakai districts plus an additional two hours of demonstrations and testimonials concerning bean production. The radio station has thousands of farmer listeners in the local area. The special program was a new initiative to create interest in bean production and 'spread the word' well beyond the IPs. Government agency officials and extension agents publically supported the research, and invited those interested to contact them for further information.
- Creation, pre-testing, and final release of a 7-minute video animation produced by Sustainable Animations Without Borders (SAWBO) that shows the four major bean recommendations in the local language (Luganda). Farmers were invited to view a draft version and made suggestions, which were then included in the final version released in October 2017 by SAWBO. It is available via the SAWBO App or website as a free download. It also is being distributed via Bluetooth by extension agents and from farmer to farmer, which requires no internet access after the initial download. Another channel is NGO partners such as CEDO, which already has shown it to more than 400 farmers to whom it provides training and seeds.

- *FIGURE 4* -

Figure 4: shows video animations of recommended practices for improved bean production in Uganda developed by SAWBO

- Creation, pre-testing and final release of a printed guide including the four major bean production recommendations. It was pre-tested in the same way as the video animation before final release. The printed guide uses still images from the video animation, printed on A4 paper in color. NARL has printed 500 copies of this guide in Luganda and another 500 in English for distribution in the area.
- Comparative testing of the video animation and the printed version was conducted with 104 farmers (men and women in both Masaka and Rakai). Results show that both communicate the recommended steps effectively and are available, depending on the distribution channel.

- TABLE 4 -

Table 4: shows farmers' knowledge gained from video animation or printed version about bean production recommendations, Masaka and Rakai, Uganda in May 2017

Mozambique:

A special version of the video animation for bean production was also created for Gurúè, Mozambique (in Lomwé language). This version is similar to the Uganda version except that the fertilizer recommendations have been adjusted for soil fertility conditions in Gurúè and other bean-production areas of the country. This version has been released by SAWBO, and is available through the SAWBO app or website. It also is being passed to farmers and extension agents by Bluetooth.

- FIGURE 5 -

Figure 5: shows selected soil properties for the surface horizon (0 to 15 cm) at releve sites on 16 model farms in Masaka and Rakai Districts, Uganda, 2014

Post-Harvest Jerry Can Bean Storage

Building on project research in 2015-2016 in Gurúè District, Mozambique, which showed that a SAWBO-produced video animation was effective in teaching farmers how to store their beans safely after harvest using jerry-can storage, researchers returned to the same two sub-districts that were used for the 2015 study to assess how many of those who watched and listened to the original video (or extension training alternative) were actually using the jerry can storage technique two years later. Approximately two-thirds of a subset of farmers who participated in the video or extension training in 2015 in two different districts were re-interviewed in July 2017. Strikingly, of 100 farmers interviewed, 91.3% had tried the jerry can storage method, and 89.4% had used it more than once, indicating that adoption was pervasive. Further, they had explained and demonstrated the method to an average of 8.5 other farmers. In addition, the evaluation found that they accurately remembered an average of 7.7 of the 8 steps involved in the process.

Both the video animation and the extension demonstration/lecture methods were effective, indicating that video animation can be used to supplement the current extension agent dissemination system. The jerry can storage experiment was especially successful because farmers had experienced severe post-harvest losses due to weevils, and they needed to safely store their seed for planting. Most already had jerry cans, so there was only minimal expense associated with adoption.

Development and Testing of Bean-Guide App for Smartphones by IIAM in Mozambique

Because most extension agents now have a smartphone or a Bluetooth-capable phone, and because more farmers are now acquiring smartphones, a supplemental grant was used to create and field test an App for Android smartphones that provides IIAM research-based recommendations for bean production in Mozambique. The App is in Portuguese, since IIAM research recommendations are in that language, and since extension agents and many farmers speak Portuguese. Version 1 of the App was created, and an early pre-test was conducted among bean extension agents and some farmers in Gurúè District, the project's focal bean growing region in Mozambique. Recommendations and suggestions resulted in revisions, and an updated version was created. In early September 2017, the App was placed on the smartphones of 10 key extension agents and 4 farmers in the area, all of whom received training in how to use it and how to share the App with others using Bluetooth. In June 2018, IIAM will conduct an evaluation of the App's use to see how extension agents and farmers have used it, and whether or not they have passed it along to others. In addition to activities in Mozambique, IIAM's communication specialist Sostino Mocumbe traveled to Uganda to demonstrate the App to agricultural scientists and extension communication staff of NARO, and to 50 computer science and more than 100 agricultural students at Makerere University.

IV. Major Achievements

- Based on results from our researcher-led field experiments in Uganda, we guided the fourth and fifth seasons of community-based field trials that have enabled farmers to learn about and test improved management practices and technologies, discuss together, and decide which practices and technologies to incorporate in their bean crop production systems. The number of farmers who have adopted some or all of the project's recommendations are 800+ in Masaka and 350+ in Rakai.
- A mapping strategy was developed using a hybrid of local knowledge and GIS; used as a basis for interpretations. One block diagram and two proof of concept soil maps were produced. These communication aides are currently being used by farmers to understand where their field resides in the context of the landscape, how that affects their crop production, and the value of various types of management practices and technologies that they might consider adopting.
- Built capacity of Innovation Platform member organizations and extension workers in sustainable soil fertility management using diagnostic and decision support aids - with and without soil testing.
- Our multistakeholder bean Innovation Platform for the Greater Masaka Region has developed in membership size, diversity, enthusiasm and capability. It is now registered as a formal cooperative organization – the Buddu Bean Farmers Primary Cooperative, comprised of 10 value chain member organizations and more than 1000 farmers. At least 25 organizations have been involved to date in supporting the IP's development. Ready markets for the beans that farmers are yet to satisfy exist including a produce trader who is also the chairperson of the IP, CEDO (buys seed), and other domestic and international buyers.
- A comparative study of innovative communication approaches for dissemination of information about legumes compared the effectiveness of four methods in increasing the knowledge that farmers have about legumes and their willingness to adopt new techniques: (1) traditional extension lecture/demonstrations; (2) video animations; (3) actual video; and (4) a printed guide (in color) using video still images and text.

Results, presented at the 2017 Grain Legume Research Conference in Burkina Faso, indicate that all four of these methods were very effective. In the experiments, all four approaches had these commonalities: (1) used a participatory initial approach that identified key problems that the farmers faced; (2) were pre-tested with farmers to ensure that the messages worked; and (3) used the local language of farmers. Local languages were least effective in the *printed* version because many farmers, especially women, had difficulty reading the local language. Video animations can be especially useful when the same message is relevant and the knowledge can be applied in several countries or many language-speaking areas.

- Project researchers presented 14 papers and posters at the Feed the Future Legume Innovation Lab Grain Legume Research Conference in Burkina Faso, August 13-18, 2017.
- At Makerere University, one M.S. student graduated, one M.S. student is near completion, and one M.S. student is progressing in his research.
- At the University of Hawai`i, one M.S. student will graduate in December 2017.
- At Iowa State University, one Ph.D. student is progressing well in program of study coursework and research activities, and is on track to graduate in May 2019.
- Three journal articles have been published based on project research results, and many others are being prepared for publication in peer-reviewed journals and dissemination in regional/national practitioner and policy outlets in Africa.
- Recommended management practices and technologies are described in print materials and animated videos for dissemination to intermediate and end users have been developed and assessed in a participatory manner, and are being disseminated.
- Capacity strengthening through applied research-based training has been achieved.

V. Research Capacity Strengthening

The breadth of our team spans soil and crop sciences, sociology, economics, extension and communications, contributing significantly to conceptualizing our research objectives, methods, data collection, analysis, interpretation and action. Members from various institutions and disciplines contribute significantly to mentoring and guiding the research of graduate students:

- Naboth Bwambale, Ph.D. student in Sustainable Agriculture and Sociology at Iowa State University, is conducting research on “Inclusive Innovation Space? Motivation and participation in a multi-stakeholder bean research innovation platform in central Uganda.”
- Lance Goettsch (M.S. 2016, ISU) was assisted by project researchers to publish two papers from his project thesis research on improved production systems for common bean in south-central Uganda on Phaeozem and Ferrasol soils in the *African Journal of Agricultural Research* in 2016 and 2017.

- Prossy Kyomuhendo, M.Sc. student in Soil Science at Makerere University, defended her thesis research on limiting nutrients and lime requirements for bean production in Leptosols and Luvisols, graduated in January 2017, and is preparing a paper for publication in *African Crop Science Journal*.
- Stewart Kyebogola, M.Sc. student in Soil Science at Makerere University, completed research on the effect of integrating organic with inorganic fertilizers on bean yield on three contrasting soils. He submitted his thesis for examination and is preparing a paper for publication.
- Sostino Mocumbe (M.S. 2016, ISU), is preparing a paper for publication in *Information Technologies & International Development* based on his thesis "Use of Animated Videos through Mobile Phones to Enhance Agricultural Knowledge and Adoption among Bean Farmers in Gurúè District, Mozambique."
- António José Rocha, M.S. student in Soil Science at the University of Hawaii, conducted research on alternative management practices for improving bean production in Gurúè, defended his thesis, was assisted by project researchers to publish one paper from his project thesis research on improving grain legume yields using local Evate rock phosphate in the *African Journal of Agricultural Research* in 2017.
- Jafali Matege, M.Sc. student in Extension Education at Makerere University, is conducting research on gender dimensions of bean farmers' decision making for soil fertility management.
- Abbas Isabirye, Ph.D. student in Agricultural and Rural Innovations at Makerere University, is examining the efficacy of the bean innovation platform in Masaka and Rakai.

Short-Term Training of Technical Staff

Two scientists from Uganda, Moses Tenywa and Onesmus Semalulu, were trained on all the latest strategies of soil mapping utilized in the USA in January 2017. This occurred in two phases: (a) professional discussions with USDA NRCS National Leaders about traditional nationwide mapping at the USDA NRCS National Soil Survey Center, and (b) through hands-on rigorous use and geospatial analysis of soils data at Iowa State University with Bradley Miller and Lee Burras. These activities resulted in their primary strategy being the soil-landscape paradigm. It enables efficient, detailed soil mapping. Then geospatial technologies were introduced because of their value for improving efficiency and consistency in that type of soil mapping. The skills acquired enabled the scientists to develop GIS-based local soil maps which were overlaid onto corresponding Google maps. Farmers were then able to interpret the improved map in terms of easily identifiable features within their locality. These maps were used as learning aids for farmers to appreciate the variation in soil types and characteristics along a landscape. Block diagrams were then drawn to represent in three dimensions the variation in soil types and their characteristics across the landscape. With this knowledge, management recommendations were jointly developed and discussed by researchers and farmers.

The project team benefitted from an Institutional Capacity Strengthening grant which involved close collaboration among the Institute of Agriculture Research of

Mozambique, Uganda's National Agricultural Research Organisation (NARO), Makerere University, and Iowa State University. IIAM communication specialist Sostino Mocumbe and ISU professor of communication Eric Abbott traveled to Kampala to demonstrate and discuss the App with agricultural scientists and extension communication staff of NARO, and to 50 computer science and more than 100 agricultural students at Makerere University. NARO's extension communication staff are now in the process of developing one or more Apps. Abbott and Mocumbe discussed overall strategies and costs for App development and maintenance with more than 40 specialists and supervisors who have been charged with App creation. At Makerere University, Abbott and Mocumbe first made presentations to students and faculty demonstrating the IIAM App and discussing the role of Apps in future agricultural communication activities. Following each meeting, the team met with faculty members from the College of Computing and Information Sciences and then with faculty members from the College of Agricultural and Environmental Sciences to initiate a collaborative process that will be used to link computer scientists and agricultural specialists in the creation of future Apps.

VI. Human Resource and Institution Capacity Development

A. Short-Term Training

1. ***Training on development and use of soil-landscape maps***
   a. Purpose of Training – development and use of soil-landscape maps
   b. Type of Training – hands-on guided experience with GIS programs
   c. Country Benefiting – Uganda
   d. Estimated USAID funding for activity
      1) US$ for Instruction = $750
      2) US$ for Participants = $2,500
      3) US$ for Travel = $4,250
   e. Location and dates of training – Ames, Iowa Jan. 8-18, 2017
   a. Number receiving training (by gender) – 2 men
   f. Home institution(s) – Makerere University, National Agricultural Research Labs
   g. Institution providing training – Iowa State University
2. ***Training on development and use of mobile phone app***
   a. Purpose of Training – development and use of mobile phone app
   b. Type of Training – demonstration and discussion
   c. Country Benefiting – Mozambique and Uganda
   d. Estimated USAID funding for activity
      1) US$ for Instruction = $500
      2) US$ for Participants = $1,835
      3) US$ for Travel = $2,810
   e. Location and dates of training – Kampala

f. Number receiving training (by gender) – 75 men, 75 women
g. Home institution(s) – Makerere University, National Agricultural Research Labs
h. Institution providing training – Institute of Agricultural Research of Mozambique, Iowa State University

B. Degree Training

Trainee #1

1. Name: Naboth Bwambale
2. Citizenship: Uganda
3. Gender: Male
4. Host Country Institution Benefitting from Training: Makerere University
5. Training Institution: Iowa State University
6. Supervising Legume Innovation Lab PI: Robert Mazur
7. Degree Program: Ph.D.
8. Field or Discipline: Graduate Program in Sustainable Agriculture *and* Sociology
9. Research Project Title: Inclusive Innovation Space? Motivation and Participation in a Multi-Stakeholder Bean Research Innovation Platform in Central Uganda
10. Estimated USAID funding for activity if not conducted in US
    a. US$ for Instruction = n/a
    b. US$ for Participants = $5,000
    c. US$ for Travel = $2,000
11. Estimated funding from other sources for activity if not conducted in US
    i. Provider of Funds = n/a
    j. US$ for Instruction = n/a
    k. US$ for Participants = n/a
    l. US$ for Travel = n/a
12. Start Date: August 2016 (following M.S. program Jan. 2014 – Dec. 2015)
13. Projected/Actual Completion Date: May 2019
14. Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
15. Training status: (active, completed, pending, discontinued or delayed): Active

Trainee #2

1. Name: Prossy Kyomuhendo
2. Citizenship: Uganda
3. Gender: Female
4. Host Country Institution Benefitting from Training: Makerere University
5. Training Institution: Makerere University
6. Supervising Legume Innovation Lab PI: Moses Tenywa
7. Degree Program for training: M.S.
8. Field or Discipline: Soil Science and Crop Production
9. Research Project Title: Limiting Nutrients and Lime Requirements for Bean Production on Three Contrasting Soils of Lake Victoria Crescent Agroecological Zone
10. Estimated USAID funding for activity if not conducted in US
    a. US$ for Instruction = n/a
    b. US$ for Participants = n/a
    c. US$ for Travel = n/a

11. Estimated funding from other sources for activity if not conducted in US
    a. Provider of Funds = n/a
    b. US$ for Instruction = n/a
    c. US$ for Participants = n/a
    d. US$ for Travel = n/a
12. Start Date: January 2014
13. Projected/Actual Completion Date: January 2017
14. Is trainee a USAID Participant Trainee and registered on TraiNet? No
15. Training status: (active, completed, pending, discontinued or delayed): Completed

Trainee #3

1. Name: Stewart Kyebogola
2. Citizenship: Uganda
3. Gender: Male
4. Host Country Institution Benefitting from Training: National Agricultural Research Laboratories
5. Training institution: Makerere University
6. Supervising Legume Innovation Lab PI: Onesimus Semalulu
7. Degree Program for training: M.S.
8. Field or Discipline: Soil Science and Crop Production
9. Research Project Title: Effect of Organic with Inorganic Fertilizers on Bean Yield in Three Contrasting Soils
10. Estimated USAID funding for activity if not conducted in US
    a. US$ for Instruction = n/a
    b. US$ for Participants = $500
    c. US$ for Travel = $1,000
11. Estimated funding from other sources for activity if not conducted in US
    a. Provider of Funds = n/a
    b. US$ for Instruction = n/a
    c. US$ for Participants = n/a
    d. US$ for Travel = n/a
12. Start Date: July 2014
13. Projected Completion Date: March 2018
14. Is trainee a USAID Participant Trainee and registered on TraiNet? No
15. Training status: (active, completed, pending, discontinued or delayed): Active

Trainee #4

1. Name: Jafali Matege
2. Citizenship: Uganda
3. Gender: Male
4. Training institution: Makerere University
5. Host Country Institution Benefitting from Training: Makerere University
6. Supervising Legume Innovation Lab PI: Richard Miiro
7. Degree Program for training: M.S.
8. Field or Discipline: Agricultural Extension Education
9. Research Project Title: Gender Dimensions of Bean Farmers’ Decision Making

for Improved Soil Fertility Management in Masaka and Rakai Districts, Uganda

10. Estimated USAID funding for activity if not conducted in US
    a. US$ for Instruction = n/a
    b. US$ for Participants = $500
    c. US$ for Travel = $1,000
11. Estimated funding from other sources for activity if not conducted in US
    a. Provider of Funds = n/a
    b. US$ for Instruction = n/a
    c. US$ for Participants = n/a
    d. US$ for Travel = n/a
12. Start Date: July 2014
13. Projected Completion Date: August 2018
14. Is trainee a USAID Participant Trainee and registered on TraiNet? No
15. Training status: (active, completed, pending, discontinued or delayed): Active

Trainee #5

1. Name: António José Rocha
2. Citizenship: Mozambique
3. Gender: Male
4. Host Country Institution Benefitting from Training: Institute of Agricultural Research of Mozambique (IIAM)
5. Training institution: University of Hawaii - Manoa
6. Supervising Legume Innovation Lab PI: Russell Yost
7. Degree Program: M.S.
8. Field or Discipline: Agronomy and Tropical Soils
9. Research Project Title: Improving Food Security of Highly Weathered Soils of Gùrué District, Mozambique
10. Estimated USAID funding for activity if not conducted in US
    a. US$ for Instruction = $4,000
    b. US$ for Participants = $21,000
    c. US$ for Travel = $10,000
11. Estimated funding from other sources for activity if not conducted in US
    a. Provider of Funds = n/a
    b. US$ for Instruction = n/a
    c. US$ for Participants = n/a
    d. US$ for Travel = n/a
12. Start Date: January 2015
13. Projected Completion Date: December 2017
14. Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
15. Training status: (active, completed, pending, discontinued or delayed): Active

VII. Achievement of Gender Equity Goals

The project team has actively promoted participation of women farmers during research activities and trainings in Uganda and Mozambique. In our short-term training, 409 women and 465 men have benefited and one woman has benefitted from long-term training.

VIII. Implementation of Data Management Plan

Quantitative and qualitative data will be archived in the USAID archive according to protocols established by the hosting agency. Data from each study will be made available in machine-readable format that does not rely on proprietary software. Each data file will be accompanied by a separate file listing and describing each parameter and the units of measurement used. For quantitative and qualitative data, these files will not rely on proprietary software for access. Papers, abstracts, posters, and other materials published by this project will be listed in a single file in the USAID data archive in one scientifically acceptable format that does not use proprietary software. Additionally, where copyright allows, published journal articles, abstracts and posters from scientific meetings, and other published materials will be archived in the Iowa State University Digital Repository. All materials in the ISU-DR are publically available world-wide to anyone with access to the world-wide-web without any sign-in or purchase required, and are readily downloadable without proprietary software.

IX. Scholarly Accomplishments

Theses completed, publications prepared or submitted for peer review:

- Goettsch Lance H., Andrew W. Lenssen, Russell S. Yost, Ebby S. Luvaga, Onesmus Semalulu, Moses Tenywa, Richard Miiro and Robert E. Mazur. 2017. “Improved production systems for common bean on Ferralsol soil in south-central Uganda” *African Journal of Agricultural Research* 12(23):1959-1969. DOI: 10.5897/AJAR2017.12122.
- Goettsch Lance H., Andrew W. Lenssen, Russell S. Yost, Ebby S. Luvaga, Onesmus Semalulu, Moses Tenywa, and Robert E. Mazur. 2016. “Improved production systems for common bean on Phaeozem soil in south-central Uganda” *African Journal of Agricultural Research* 11(46):4796-4809. DOI: 10.5897/AJAR2016.11760.
- Rocha António, Ricardo Maria, Unasse S. Waite, Uatema A. Cassimo, Kim Falinski and Russell Yost. 2017. “Improving grain legume yields using local Evate rock phosphate in Gùrué District, Mozambique.” *African Journal of Agricultural Research* 12(22):1889-1896. DOI: 10.5897/AJAR2017.12331.
- Bello Julia, Anne Namatsi Lutomia, Eric Abbott, Robert Mazur, Sostino Mocumbe, and Barry Pittendrigh. 2017. “Making Agricultural Learning Accessible: Examining Gender in the Use of Animations via Mobile Phones” (5:74-100) in M. Mills and D. Wake (eds.) *Empowering Learners with Mobile Open-Access Learning Initiatives*. Hershey PA: IGI Global. DOI: 10.4018/978-1-5225-2122-8.ch005.

- Kyomuhendo, Prossy. 2017. “Limiting Nutrients and Lime Requirements for Bean Production on Three Contrasting Soils of Lake Victoria Crescent Agroecological Zone.” M.Sc. thesis, Makerere University.
- Rocha, António José. 2017. “Improving food security of highly weathered soils of Gùrué district, Mozambique.” M.Sc. thesis, University of Hawai’i at Manoa.

Scientific paper presentations and posters were prepared and presented at the Feed the Future Legume Innovation Lab Grain Legume Research Conference, Ouagadougou, Burkina Faso - 13 to 18 August 2017 (listed below in alphabetical order by lead author):

- Abbott E, Miiro R, Mazur R, Mocumbe S, Pittendrigh B, Bello-Bravo J, & J Matege. “Comparative effectiveness of video animation delivered by smartphones versus printed images in communicating bean-growing recommended practices to farmers in Uganda and Mozambique.” (paper presentation)
- Bello-Bravo J, Dannon A, Zakari O, Laouali A, Baoua I, Tamò M & B Pittendrigh. “An assessment of localized animated educational videos (LAV) versus traditional extension presentations or LAV followed by extension agent discussions among farmers in Benin and Niger.” (paper presentation)
- Bwambale N & R Mazur. “Inclusive innovation space: The bean value chain innovation platform in Masaka district, central Uganda.” (paper presentation)
- Luvaga E, Mazur R, Miiro R, Kyebogola S, Kabango F, Matege J, Abbott E, Semalulu O & M Tenywa. “Utilizing imperfect and inconsistent data: Economic feasibility analysis of common bean production in Uganda and Mozambique.” (paper presentation)
- Maria R. “Optimizing fertilizer application in common bean (Phaseolus vulgaris L.) in Gurúè, northern Mozambique.” (paper presentation)
- Mazur R, Bwambale N, Miiro R, Tenywa M, Semalulu O & E Abbott. “Development and Lessons Learned from a Bean Innovation Platform in Uganda.” (paper presentation)
- Mazur R, Miiro R, Abbott E, Tenywa M, Luvaga E & O Semalulu. “Social and economic factors in farmer decision making for improved soil fertility management and bean production in Uganda.” (paper presentation)
- Miller B, Burras L, Semalulu O, Kizza C, Majaliwa J, Tenywa M & R Mazur. “Strengthening the indigenous soil classification system using GIS-based mapping of the Buganda catena, Uganda.” (paper presentation)
- Mocumbe S, Abbott E, Mazur R & and R Maria. “Rapid Appraisal of a mobile app linking researchers with extension officers and bean farmers in Gurúè District, Mozambique.” (paper presentation)
- Rocha A, Maria R, Cassimo U, Glazer C, Crow S, Rajan S & R Yost. “Evate rock phosphate: A potential regional source of a nutrient input for acid, impoverished soils of Gurúè district, Mozambique.” (poster)

- Rocha A, Maria R, Waite U, Cassimo A & R Yost. “Improving pigeon pea and common bean yields in Gurúè district, Mozambique.” (poster)
- Rocha A, Sandlin M, Yost R & R Maria. “Crop management strategies in the Mepuagíua community, Gurúè district. (poster)
- Semalulu O, Kyebogola S, Tenywa M, Miiro R, Lenssen A, Yost R, Abbott E & R Mazur. “Fine-tuning research findings to famer decision making in soil fertility management: From bean fertilizer recommendations to farm level action.” (poster)
- Tenywa M, Semalulu O, Miiro R, Kyebogola S, Kyomuhendo P, Kiiza C, Majaliwa J, Nampijja J, Lenssen A & R Mazur. “Developing a methodology for mapping local soil types along the Buganda Catena, Uganda.” (paper presentation)

Posters presented at the 18th Annual World Bank Conference on Land and Poverty: Responsible Land Governance - Towards an Evidence-Based Approach. Mar. 20-24, 2017. Washington, D.C.

- Mazur R, Bwambale N, Abbott E & M Tenywa. "Land Rights and Farmer Decision Making for Productivity and Soil Fertility Management in Uganda and Mozambique."
- Bwambale N, Mazur R & E Abbott. "Perceived Land Tenure Security and Investment in Integrated Soil Fertility Management Practices among Smallholders in Masaka District, Central Uganda."

X. Achievement of Impact Pathway Action Plan

The research team and in-country collaborating organizations have jointly achieved all Key Project Outputs as envisioned in the Impact Pathway Action Plan for improved soil fertility management and increased bean productivity, with details contained in the preceding sections:

- Process for identifying alternative strategies and management practices and technologies
- Effective and efficient methods and media for information dissemination to intermediate and end users developed and assessed – the principal end users are farmers, extension agents, farmers' associations, development organizations, and agriculture agency staff
- Capacity building through applied research-based training conducted
- Results of research produced in various formats for an array of stakeholders – these are being shared with farmers, extension agents, farmers' associations, development organizations, agriculture ministry staff, and research scientists.

The project team's Vision of Success has been realized:

- Increased effectiveness & efficiency in determining constraints & solutions for sustainably implementing investments in bean productivity and soil fertility in Uganda & Mozambique
- Widespread use by farmers of diagnostic and decision support aids to solve problems - in Uganda and Mozambique, and available for use elsewhere.

ANNEXES

Annex 1. Tables, Figures, and Photos Cited in the Report

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes

Report on the Achievement of "Milestones of Progress"
(For the Period: April 1, 2016 – September 30, 2016)

This form should be completed by the U.S. Lead PI and submitted to the MO by September 29, 2017

Project Title: SO2.1 - Farmer Decision Making Strategies for Improved Soil Fertility Management in Maize-Bean Production Systems

	Abbreviated name of institutions																	
	Iowa State University			University of Hawaii			University of Illinois			Makerere University			Nat'l Ag. Res. Lab - Ug.			Inst. Ag. Res. - Moz.		
	Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved	
Milestones by Objectives	9/29/17	Y	N*	9/29/17	Y	N*	9/29/17	Y	N*	9/29/17	Y	N*	9/29/17	Y	N*	9/29/17	Y	N*
	(Tick mark the Yes or No column for identified milestones by institution)																	
Objective 1	Characterize Smallholder Farmers' Motivations, Current Knowledge and Practices																	
1.1 Reports Commun. Learning vis. On-Farm Trials-Ug	X			0			0			X			X			0		
1.2 Reports Commun. Learning vis. Field Days-Moz	X			0			0			0			0			X		
1.3	0			0			0			0			0			0		
1.4	0			0			0			0			0			0		
1.5	0			0			0			0			0			0		
Objective 2:	Develop and Refine Models about Smallholder Bean Farmers' Decision Making																	
2.1 Reports, Innovation Platform Activities & Outcomes	X			0			0			X			X			0		
2.2 Reports, Farmers' Adoption Mgmt. Practices/Tech.	X			0			0			X			X			X		
2.3 Updated Models of Farmer Decision Making	X			0			0			X			X			X		
2.4 Recommendations for Training & Support	X			X			0			X			X			X		
2.5	0			0			0			0			0			0		
Objective 3:	Develop and Validate Diagnostic and Decision Support Aids (DDSA)																	
3.1 Updated Reports On-Farm Trials on Bean Crop Mgmt.	X			X			0			X			X			X		
3.2 Updated Recommendations Bean Crop Mgmt. System	X			X			0			X			X			X		
3.3 Participatory Assessment of All DDSA	X			0			X			X			X			X		
3.4 Refined and Finalized DDSA	X			X			X			X			X			X		
3.5	0			0			0			0			0			0		
Objective 4:	Develop and Assess Effectiveness of Innovative Approaches for Dissemination																	
4.1 Analyses of Media & Training Effectiveness	X			0			X			X			X			X		
4.2 Message & Media for Dissem. of All DDSA	X			0			X			X			X			X		
4.3 Particip. Assess. of Message & Media for All DDSA	X			0			X			X			X			X		
4.4 Strategy for Dissemination of All DDSA	X			0			X			X			X			X		
4.5	0			0			0			0			0			0		
Name of the PI reporting on milestones by institution	Robert Mazur			Russell Yost			Barry Pittendrigh			Moses Tenywa			Onesimus Semalulu			Ricardo Maria		

Name of the U.S. Lead PI submitting this report to the MO: Robert Mazur

Signature **Date**

* *Please provide an explanation for not achieving the milestones on a separate sheet.*

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes
REVISED PERFORMANCE INDICATORS / TARGETS SPREADSHEET for FY 14, FY 15, FY16, and FY 17

Project HSO2.1

Institution 6 Name (one sheet per institition):

Indic. numbe	Output Indicators	FY 14 Target	FY 14 Revised	FY 14 Actual	FY 15 Target	FY 15 Revised	FY 15 Actual	FY 16 Target	FY 16 Revised	FY 16 Actual	FY 17 Target	FY 17 Revised	FY 17 Actual	FY18 Target	FY 18 Revised	FY 18 Actual
		(October 1, 2013 - September 30, 2014)			(October 1, 2014 - September 30, 2015)			(October 1, 2015 - September 30, 2016)			(October 1, 2016 - September 30, 2017)			(Oct 1, 2017 - Nov 30, 2017)		
1	4.5.2(6) Degree Training: Number of individuals who have received degree tra	0	0	0	7	6	6	8	8	8	4	6	5	0	0	0
	Total number by sex	5	5	5	7	6	6	8	8	8	4	6	5	0	0	0
	Number of women	1	1	1	1	1	1	1	1	1	0	1	1			
	Number of men	4	4	4	6	5	5	7	7	7	4	5	4			
	Total number by New/continuing	0	0	0	7	6	6	8	8	8	4	6	5	0	0	0
	New	0	0	0	1	1	1	0	0	0	0	0	0			
	Continuing	0	0	0	6	5	5	8	8	8	4	6	5			
2	4.5.2(7) Short-term Training: Number of individuals who have received short-	7	5	5	0	0	0	0	0	0	0	235	798	0	0	0
	Total number by sex	7	5	5	8	8	172	71	71	2138	43	235	798	0	0	0
	Number of women	2	2	2	3	3	64	26	26	1141	21	121	368			
	Number of men	5	3	3	5	5	108	45	45	997	22	114	430			
	Numbers by Type of individual	7	5	5			172	71	71	2138	43	235	798	0	0	0
	Producers	0	0	0	0	0	57	14	14	2008	14	170	385	0	0	0
	Number of women									1084	0	100	182			
	Number of men									924	0	70	203			
	People in government	7	5	5	8	8	78	43	43	60	15	28	206	0	0	0
	Number of women									26	0	8	92			
	Number of men									34	0	20	114			
	People in private sector firms	0	0	0	0	0	17	6	6	40	6	17	81	0	0	0
	Number of women									20	0	6	33			
	Number of men									20	0	11	48			
	People in civil society	0	0	0	0	0	20	8	8	30	8	20	126	0	0	0
	Number of women									11	0	6	61			
	Number of men									19	0	14	65			
7	4.5.2(39) Number of new technologies or management practices in one of the following phases of development: (Phase I/II/I									2	2	7				
	Phase 1: Number of new technologies or management practices under research as a result of USG assistanc	2	1	1	2	2	1	1	1	1	0	2	2			
	Phase 2: Number of new technologies or management practices under field testing as a result of USG assistanc	0	0	0	0	0	0	1	1	1	2	4	6			
	Phase 3: Number of new technologies or management practices made available for transfer as a result of USG assistanc	0	0	0	0	0	0	0	0	0	0	1	1			

Notes:

These indicators are developed under the Feed the Future Monitoring System. Please provide 'total' numbers and also disaggregate where applicable. Just providing 'totals' will not be approved.

This table corresponds to the Feed the Future Performance Indicators data collection sheet under the FTFMS system. Where an indicator does not apply to the type of work done under the project, leave it blank.

Please follow the indications in the Legume Innovation Lab Indicators Handbook that will be provided to you by the Management Office. Contact Mywish Maredia (maredia@anr.msu.edu) for further information.

There is additional guidance on the USAID Microlinks website: http://agrilinks.org/sites/default/files/resource/files/FY14%20FTFMS%20Guidance_2.pdf

X. Enhancing Pulse Value-Chain Performance through Improved Understanding of Consumer Behavior and Decision-Making (SO2.2)

Lead U.S. Principal Investigator and University:
Vincent Amanor-Boadu, Kansas State University

Collaborating Host Country and U.S. PIs and Institutions:
Gelson Tembo, University of Zambia
Lawrence Mapemba, Lilongwe University of Agriculture and Natural Resources, Malawi
Fredy Kilima, Sokoine University of Agriculture, Tanzania
Allen Featherstone, Kansas State University
Kara Ross, Kansas State University

I. Abstract of Research and Capacity Strengthening Achievements

During FY2016-2017, national conferences on Beans for Health and Wealth were held in Malawi and Zambia with over 300 participants at each of the national conferences. These conferences allowed us to share their key research findings with industry stakeholders. Six workshops on improving inter-organizational relationship capacities and the bean industry's overall income were held across Malawi and Zambia. These workshops were well attended with each workshop having 50 or more participants. In the past year, we have developed an innovative approach to assessing the relative positions of food groups in food hierarchies. We have also identified preferred bean products in Malawi, Zambia, and Tanzania. This information is of interest to bean supply chain members, particularly bean breeders, and can used to enhance overall chain performance. Knowledge of the food hierarchies combined with the bean product preferences allows us to provide bean supply chain participants with valuable information to improve overall chain performance and improve production and marketing decisions to create wealth along the chain and reduce poverty. To date, 29 students have been recruited for this project and 19 have completed their degree training from partner institutions and at Kansas State University.

II. Project Problem Statement and Justification

Grain legumes are not traditional staples in Zambia, Malawi, and Tanzania. They are not the priority crops for policymakers or breeders, traders or regulators. However, grain legumes present significant opportunities for many farmers and traders who produce and sell them. Developing an improved understanding of how consumers make their decisions and an appreciation of the factors supporting these decisions could provide insights into how policymakers and the grain legume trade develop policies and strategies to enhance the contribution of grain legumes to overall economic progress. Given the health and nutritional benefits of grain legumes, identifying strategies that improve their consumption could contribute to improving overall health of individuals in these countries and potentially reduce their health budgets. These results may be scaled into other countries with similar population profiles.

The primary problem this project sought to address was developing an innovative approach to understanding factors that influence and shape consumers' food choices in three Feed the Future focus countries (Zambia, Malawi, and Tanzania). We also intended to identify the bean varieties of choice in these countries to inform bean breeders, helping them enhance the performance of the whole supply chain and not just producers.

The project was organized into three integrated dimensions:

(i) Develop an empirical foundation for understanding the position of legumes in the food hierarchy and the factors that could improve this position;

(ii) Identify opportunities for enhancing the position of legumes in the food hierarchy in each country; and

(iii) Work directly with the legume trade and its supporters to develop individual and collective processes to take advantage of the knowledge emanating from the research to enhance their individual and collective economic performance.

The three focus countries represent the changes occurring in eastern and southern Africa—increasing urbanization; economic growth and increasing but unequally distributed incomes. This research will provide insights into how and where these changes are affecting legume consumption. They will provide insights into how these markets can overcome domestic consumption barriers to build stronger value chains to seize new markets.

III. Technical Research Progress

Objective 1: Identify and analyze the principal factors shaping legume consumption and their relative positions in consumers' food rankings in the selected countries.

Approaches and Methods

The project team collected primary data in three countries covering the project's scope and employed statistical and discrete choice experiment methods to complete objective one. We used the statistical methods to construct a food hierarchy for the six major food groups in the Malawi, Tanzania and Zambia. We used the discrete choice experiment to identify the relative importance of the different characteristics of beans in the selected countries. Our purpose is two-fold. Knowing legumes' rung on the food hierarchy will help in an assessment of the challenge associated with altering consumption habits to improve legume demand. Second, identifying the relative importance of different bean characteristics to consumers, we hope to inform breeding-to-market strategies to enhance total chain economic performance.

Results, Achievements and Outputs of Research:

Legumes' position in the food hierarchy in each of the three countries was determined in relation to five other food groups: roots and tubers; fish; meat and animal products; cereals; and fruits and vegetables. To establish positions, we used the per capita share of food budget allocated to each food group and the food group' criticality to the household's food and nutrition security. Our results show that legumes sat on the second rung from the bottom, ahead of roots and vegetables, in Malawi and Zambia, but on the fourth rung from bottom in Tanzania, ahead of roots and tubers, fruits and vegetables and meat and animal products. We surveyed about 680 people in Malawi, 740 in Tanzania and 841 in Zambia to conduct the primary analysis.

Knowing legume's position in the hierarchy is not enough; we also need to know how far it is from the other food groups. We described the percentage difference between legumes' rung score and that of the other food groups as distance measured in "degrees". This allowed us to estimate that cereals were 194° above legumes while fish was only 23° in Tanzania. Contrarily, roots and tubers were 63° below legumes while fruits and vegetables and meat and animal products were respectively 5° and 3° below legumes. In Zambia, cereals and meat and animal products were 101° and 129° respectively above legumes while roots and tubers were 35° below legumes. Fruits and vegetables and fish were respectively 34° and 71° above legumes. We determined that cereals were 206° above legumes in Malawi, followed by meat and animal products, fish and fruits and vegetables at 156°, 83° and 52° above respectively. We estimated roots and tubers to be 30° below legumes in Malawi. Across the three countries, there are very different pattern in the relative distance of the different food groups from legumes, which suggests the need for unique strategies to enhance legumes' position in the food hierarchy in each country. Estimated Kendall's Coefficient of Concordance for each of the countries confirms that there is no statistically significant concordance among the rankings of the food groups in any of the three countries. This further underscores the importance of pursuing different strategies to enhance legumes' position in the food hierarchy in each of the countries.

We identified color, grain size, cooking time and gravy quality as the critical attributes of interest to consumers through expert, trader, retailer and consumer interviews in the selected countries. Malawi consumers generally preferred fast-cooking medium-size red mottled beans with good quality gravy. In Tanzania, the typical preference across all product offerings was fast-cooking medium-size Njano bean with good gravy quality. A fast-cooking large-size purple bean (Kablengeti) with good gravy quality is the preferred bean product in Zambia. Across all three countries, consumers seemed to be more flexible with the color and size of their beans than they were with fast-cooking time and good quality gravy. Presenting consumers with a budget constraint accentuated their preferences for these non-negotiable product characteristics. Breeders would do well to focus on selecting for cooking time and gravy quality in order to build value innovation across the supply chain.

Expenditure is a product of quantity and price. Given that prices of the same product could differ because of the relative bargaining power of the participants in the exchange at any time, we have chosen not to disaggregate expenditure. We hypothesized that legume expenditures will be determined by respondents' gender, age, household size, income in quintiles, education in categories (none, primary, secondary, technical/vocational and university/college), expenditure on other food groups and the types of food legumes were paired with. The statistically significant factors influencing the legume expenditures in the three countries are as follows[2]:

[2] Statistical significant is determined at 5% or lower significant level.

- Household size was statistically significant in all three countries. In Tanzania, expenditure on legumes increase by TSH 3,261.39 for each additional household member. In Malawi, an additional household member increased expenditure on legumes by MWK 124.66. In Zambia, it was ZMK 2.23 for each additional household member. A percentage increase in household size increased legume expenditure by 0.23% in Zambia, 0.46% in Tanzania and 0.25% in Malawi.
- Being separated or divorced and widowed decreased expenditure on legumes in Malawi by about MWK 1,200. On the other hand, households headed by the widowed in Tanzania had TSH 8,848.24 less expenditure on legumes than households with unmarried or single individuals. Marital status had no effect on legume expenditure.
- While the third and fourth income quintiles in Malawi exhibited a statistically significant increase in legume expenditure over the first quintile, the second and the fifth were not statistically different. Income by quintiles had no effect on legume expenditures in Zambia.
- In Malawi, part-time employment, whether salaried or self-employed, was not statistically different from unemployed respondents even though the coefficients were positive. However, being full-time salaried or self-employed increased expenditure on legumes by MWK 955.94 and MWK 823.73 respectively. In both Tanzania and Zambia, employment type did not explain legume expenditures.
- Age had a small but positive effect on legume expenditure in Malawi, increasing by MWK 17.84 for each year in the age of the respondent. Contrarily, age was not significant in explaining legume expenditure in Tanzania and Zambia.
- A percentage increase in root crops expenditures increased legume expenditure by 0.18% in Zambia. In Tanzania, a percentage increase in cereal and root crops expenditures increase legume expenditures by 0.30% and 0.09% respectively. In Malawi, a percentage increase in fish and cereals expenditures increased legume expenditures by 0.10% and 0.13% respectively.
- Although accounting for only 17% of respondents in Malawi, households that paired beans with plantains or banana spent MWK 669.58 more on legumes than those who did not. No other food pairing presented a statistically significant coefficient. No paired food group presented a statistically significant relationship with legume expenditure in Tanzania and Zambia.

The foregoing suggests some strategic initiatives that may be used to improve legume expenditures, which as indicated may be consumers' willingness to pay higher prices, consume more, or do both. Policies and marketing efforts must focus on larger households in all three countries and on households headed by older people in Malawi. The extent of complementarity in Tanzania between cereals and legumes is higher than in the other countries. This could be because legumes as an accompaniment to the staple maize has not been *discovered* in Zambia and Malawi. Recipe education initiatives on TV and other visual media could help address this challenge. In Malawi, it is important that alternative starches, such as plantains and bananas, be incorporated in these recipes since the results suggest a positive pairing effect with legumes.

Objective 2: Conduct situation analyses for legume production and marketing/distribution systems with a view to identifying the nature and extent of the gaps in their value chains.

We used secondary data available from the World Bank and the Food and Agriculture Organization of the United Nations to conduct the production and marketing/distribution situation for beans in Malawi, Tanzania and Zambia. We employed trend analyses and econometric analyses as our analytical tools. The datasets used for Malawi and Tanzania were the World Bank's nationally-representative Living Standards Measurement Survey – Integrated Survey on Agriculture (LSMS-ISA) and the Food Security Research Project (FSRP) dataset for Zambia.

Results, Achievements and Outputs of Research:

Zambia's bean production is the lowest among the three countries and has remained virtually flat over the past decade. This is probably related to Zambia having the lowest per capita consumption of beans among the three countries, about a quarter to a third of what prevails in the region. Thus, consumption is the principal driver of production. On the other hand, bean production in both Malawi and Tanzania have been increasing since the turn of the century at an average annual rate of about 7.3% and 6.5% per annum. Although Malawi's production of 58,277 MT was only about 10.7% that of Tanzania's in 2000, it had increased to nearly 17% by 2014 with Malawi producing nearly 190,000 MT. This trend in Malawi has been supported by price increases in significant organization of farmers into horizontal alliances. For example, the Grain and Legume Association (GALA) has organized more than 200,000 farmers into associations and farmer cooperatives that are working on facilitating input procurement and product sales. Such development has not been pursued in Tanzania. These farmers have increased the land planted to beans from under 144,000 ha in 2000 to almost 330,000 ha by 2014, an increase of almost 130%. They have also benefited from yield improvement, but not as dramatic as harvested area, about 41% over the same period. The improvements in area and yield in Tanzania were comparatively smaller, 68.7% and 22.3% between 2000 and 2014.

Because of the low production in Zambia, we know a lot less about downstream activities in Zambia's bean industry compared to the Malawi and Tanzania. Contributing to addressing this gap, our work has shown that traders are not only important in the supply chain, but their business and demographic characteristics influence prices. Sichilima, Mapemba and Tembo (2016) showed that the market where traders operate in Zambia influenced the types of beans they sold and the prices they received. This is important because it illuminates how these traders engage with farmers upstream in their supply chain and influences how much they can afford to pay in their bean procurement decisions. We found that although product handling and its effect on quality and price has not received a lot of attention in the bean industry in the region, damaged beans put about a 10% discount on bean in Zambia. Despite the lack of formal knowledge on this, we discovered traders and retailers sorting beans manually – separating damaged grain and dockage to improve quality presented to the consumer. In some cases, they sorted beans by color, one grain at a time, with the view of achieving a superior presentation. It is important to note that traders are one of the alternative channels available to farmers. The others include non-governmental organizations and government institutions, such as prisons and the military. There is a gap in our knowledge about how these other channels influence performance in the bean supply chain. We will continue our research after the end date of this program and will develop policy briefs to help develop public policy and private initiatives to enhance supply chain performance and improve the economic well-being of chain stakeholders.

Graduate students at Kansas State University, Lilongwe University of Agriculture and Natural Resources, and Sokoine Agricultural University are also continuing this research in bean production and consumption and using it to fulfill their thesis requirement. A number of undergraduate research papers are currently under review by host country PI and other senior researchers at the University of Zambia. A number of research studies have already been published and presented at professional meetings in the US and abroad and in project-sponsored conferences in Malawi and Zambia. Additionally, these theses and research papers emanating from the research project are currently being developed for peer-reviewed publications co-authored by senior project researchers and their students.

Objective 3: Implement formal and informal capacity building initiatives to address identified gaps and support value chain management capacity across the legume industry in the focus countries.

This project has maintained a close relationship with producers and their downstream partners in the countries in which we have operated. Because of the strength of local partnerships in Malawi, we were more successful in penetrating local industry and building closer ties for capacity development. For example, developing a closer relationship with the Grain and Legume Association (GALA) in Malawi was critical in facilitating direct access to producers and their customers. We would suggest that future projects work on identifying **willing and able partners** very early to enhance dissemination of information and capacity building. While we discovered that individuals were open to agreeing to work with us, we realized that because of the depth of work involved in organizing, engaging and driving for results, many of them who did not fully appreciate the mission were unable to make the necessary investment to achieve the results. Therefore, it is important that project not only seek organizations that are willing to collaborate, but identify individuals who are able to understand the mission and its potential effect on their constituents in order to make the commitment to engage. We benefited from such a relationship with the leadership of GALA, in in particular Mr. Kennedy Munyapala, GALA's Executive Director. Over the life of the project, we engaged more than 1,250 farmers and their downstream partners in capacity building and information sharing activities. About 40% of the participants were females. We did these engagements through hosting 16 workshops and two national conferences. The workshops took place in all three countries but the conferences were held only in Malawi and Zambia. Our graduate education strategy was to support local partners with the supervision of graduate students supported by the program. In total, we supported 29 graduate students in this project, 15 of whom are females. Nineteen students have completed their degree training while 10 students remain active in their program of study. The students' work and those of their mentors are also being organized into presentations at professional meetings and into peer review publications.

Results, Achievements and Outputs of Research:

- The "Beans for Health and Wealth" national conference was held March 14-15, 2017 in Lilongwe, Malawi and its objective was to inform participants about the Zambian bean market and its consumers.
- A similar national conference was held in Lusaka, Zambia on June 7-8, 2017.
- Over 300 participants attended the conference in Lilongwe. On the first day of the conference in Lusaka, over 300 participants attended and 250 attended on the second day in Lusaka. Conference participants included breeders and researchers, farmers and "aspiring farmers", bean and other commodity traders, bean processors, seed and fertilizer suppliers, and government and non-government personnel.
- Topics discussed at the conference included consumer preferences for the different characteristics of beans in the three countries, breeding initiatives, and nutrition policies and programs promoting bean consumption in Zambia and in the southern African region.
- Three workshops in three locations/regions were conducted across Malawi and Zambia. The workshops' objective is to help industry stakeholders build in their inter-organizational relationship capacities, understand the importance of leveraging trust and relationships to enhance their performance, and improve industry's overall income. The locations in Malawi were Lilongwe, Blantyre, and Mzuzu and the Zambian locations were Lusaka, Kitwe and Livingstone. The Lilongwe workshop was held on March 17, 2017 and about 60 participants attended. The workshops in Blantyre (50 participants) and Mzuzu (60 participants) were held on March 20 and 22, 2017, respectively. The Lusaka workshop took place on June 9, 2017 and had about 75 participants encompassing the bean supply chain. The workshop in Kitwe and Livingstone will take place on June 12 and on June 14, 2017, respectively and approximately 50 participants attended in each of the locations.
- At the national conference in Zambia, conference participants on their own, i.e., without any prompting from organizers, initiated the formation of a stakeholder group they dubbed Legume Consumption Promotion Association of Zambia. About 60 participants signed up with an objective to move some of the lessons

from the conference forward into value opportunities for industry stakeholders.

IV. Major Achievements

- Determined how far beans are from the center of plate. Private and public policymakers can use this information to develop the appropriate policies and strategies to move beans and other legumes to the center of plate to enhance their contribution to the health of their customers and populations and improve the incomes of the upstream bean and legume supply chain.
- Discovered that bean grain size, color, gravy quality and cooking time were important determinants of consumer preference. Our work now involves engaging breeders to help them appreciate what we are calling "Breeding for Supply Chain Performance," an initiative that uses consumer preference information to develop varieties that increase the financial performance of all stakeholders at the different stages in the supply chain in different markets.
- Held the first national conference on beans (as a strategic crop for wealth and health) in both Malawi and Zambia. Local organizations in Malawi see this critical to their overall growth that they are planning to organize a sequel next year.
- Held six strategic alliance workshops across Malawi and Zambia.
- Trained 12 graduate students at the MS level and 3 students at the MAB level. Four out of the 12 MS students have completed their degree and 1 MAB student completed her degree.
- Contributed to enhancing the business and management capacity of more than 1,250 industry players.
- Completed more than 8 policy briefs, delivered 20 oral and poster presentations at academic conferences and industry training sessions. Currently working on translating presented research papers into peer-reviewed publications involving students and project principal investigators.
- Through close engagement with industry participants in Malawi and Zambia, we are continuing to provide support for industry initiatives the have emerged from our activities.
- Built strong industry relationships with project investigators in host countries.

V. Research Capacity Strengthening

The project worked with host country partners in the supervision of the theses for students. In doing this, we helped our host country partners to use alternative tools and mentorship mechanisms with their students. We also helped students appreciate the scientific approach. As noted by one student in Malawi, "I wish I had had the opportunity to work with this team throughout my education program." We also included host country students in organizing and preparing for the national conferences. Although they did not present any papers at the event themselves, they provided rapporteur support for the conferences and the workshops.

We did not purchase any equipment over $5,000 for any our host country partners in support of research capacity strengthening.

VI. Human Resource and Institution Capacity Strengthening

10. Short-Term Training

Our main HR and institutional capacity strengthening in 2016/17 was on industry institutions. We built these into the national conferences and workshops we hosted in Malawi and Zambia. We have reported the results and achievements from these under the Results and Achievements section above.

We recognized that to organize a two-day national conference that covered both the public and private sectors would require significant local organization that the project was not structured to have. To over this, we sought permission and approval from the Management Office to award a contract to a local event management company to provide the requisite services. The contract was structured to cover a two-day conference and three full-day workshops in three different cities in Malawi and Zambia. Tanzania was not included in these programs due to instruction from the MO. However, our Tanzanian host-country PI was involved in all programming in the other two countries.

We negotiated a fixed cost contract with a local event management company in Malawi that had regional event staging experience, Ovation Advertising. The contract was for a total of $141,945. This was distributed between the two countries as follows: Malawi - $75,255; and Zambia - $66,690. We had assumed that we will spend about $100/person for all events – conferences and workshops in both countries. Based on our budget, we were expected about 1,420 participants in the events. Given that total number of participants (counting conference participants on both days as independent) was 1,535, we gained in our expenses, coming in at about $92.47, about 7.5% below our budgeted cost per person. Thus, for the same amount of money, we were able to reach about 8.1% more people.

	Short Training 1	**Short Training 2**
Purpose of Training	To help bean industry stakeholders' strategic alliances to enhance their performance and improve bean industry's overall income	To help bean industry stakeholders' strategic alliances to enhance their performance and improve bean industry's overall income
Type of Training	Workshop	Workshop
Country Benefitting	Malawi	Malawi
Estimated USAID funding for activity: US$ for Instruction		
Estimated USAID funding for activity: US$ for Participants		
Estimated USAID funding for activity: US$ for Travel		
Location and Dates of Training	March 17, 2017 at Lilongwe	March 20, 2017 at Blantyre
Number receiving training (Male)	31	35
Number receiving training (Female)	29	15
Home institution(s) (if applicable)		
Institution providing training or mechanism	KSU, LUANAR, SOIKOINE, UNZA	KSU, LUANAR, SOIKOINE, UNZA

	Short Training 1	**Short Training 2**
Purpose of Training	To help bean industry stakeholders' strategic alliances to enhance their performance and improve bean industry's overall income	To help bean industry stakeholders' strategic alliances to enhance their performance and improve bean industry's overall income
Type of Training	Workshop	Workshop
Country Benefitting	Malawi	Zambia
Estimated USAID funding for activity: US$ for Instruction		
Estimated USAID funding for activity: US$ for Participants		
Estimated USAID funding for activity: US$ for Travel		
Location and Dates of Training	March 22, 2017 at Mzuzu, MW	June 9, 2017 at Lusaka, ZM
Number receiving training (Male)	42	50
Number receiving training (Female)	18	25
Home institution(s) (if applicable)		
Institution providing training or mechanism	KSU, LUANAR, SOIKOINE, UNZA	KSU, LUANAR, SOIKOINE, UNZA

	Short Training 1	Short Training 2
Purpose of Training	To help bean industry stakeholders' strategic alliances to enhance their performance and improve bean industry's overall income	To help bean industry stakeholders' strategic alliances to enhance their performance and improve bean industry's overall income
Type of Training	Workshop	Workshop
Country Benefitting	Zambia	Zambia
Estimated USAID funding for activity: US$ for Instruction		
Estimated USAID funding for activity: US$ for Participants		
Estimated USAID funding for activity: US$ for Travel		
Location and Dates of Training	June 12, 2017 at Kitwe, ZM	June 14, 2017 at Livingstone, ZM
Number receiving training (Male)	35	40
Number receiving training (Female)	15	10
Home institution(s) (if applicable)		
Institution providing training or mechanism	KSU, LUANAR, SOIKOINE, UNZA	KSU, LUANAR, UNZA

11. Degree Training in the US or elsewhere

	Student 1	Student 2
Name	Moses Chitete	Dorothy Chisusu
Country of Citizenship	Malawian	Malawian
Gender	Male	Female
HC Institution to Benefit from Training	LUANAR	LUANAR
Training Institution	LUANAR, Malawi	LUANAR, Malawi
Supervising LIL PI	Dr L. Mapemba	Dr L. Mapemba
Degree Program for training	Master of Science	Master of Science
Field or Discipline	Agricultural and Applied Economics	Agricultural and Applied Economics
Thesis Title/Research Area	Market Structure, Conduct and Performance of Beans Marketing System in Malawi	Contribution of common beans to household dietary diversity and calorie consumption in Malawi
Estimated USAID funding for activity if not conducted in US: US$ for Instruction		
Estimated USAID funding for activity if not conducted in US: US$ for Participants		
Estimated USAID funding for activity if not conducted in US: US$ for Travel		
Estimated OTHER funding for activity if not conducted in US: US$ for Instruction		
Estimated OTHER funding for activity if not conducted in US: US$ for Participants		
Estimated OTHER funding for activity if not conducted in US: US$ for Travel		
Start Date (month/year)		
Projected Completion Date (month/year)	2017	2017
If enrolled at a US university, will Trainee be a "Participant Trainee" as defined by USAID?	N/A	N/A
Training status	Completed	Completed

	Student 1	Student 2
Name	Yanjanani Lifeyo	Edwin Kenamu
Citizenship	Malawian	Malawian
Gender	Male	Male
HC Institution to Benefit from Training	LUANAR	LUANAR
Training Institution	LUANAR, Malawi	LUANAR, Malawi
Supervising LIL PI	Dr L. Mapemba	Dr L. Mapemba
Degree Program for training	Master of Science	Master of Science
Field or Discipline	Agricultural and Applied Economics	Agricultural and Applied Economics
Thesis Title/Research Area	Market participation of smallholder common bean farmers in Malawi: A Triple Hurdle Approach	Consumers' willingness to pay for bean attributes in Malawi
Estimated USAID funding for activity if not conducted in US: US$ for Instruction		
Estimated USAID funding for activity if not conducted in US: US$ for Participants		
Estimated USAID funding for activity if not conducted in US: US$ for Travel		
Estimated OTHER funding for activity if not conducted in US: US$ for Instruction		
Estimated OTHER funding for activity if not conducted in US: US$ for Participants		
Estimated OTHER funding for activity if not conducted in US: US$ for Travel		
Start Date (month/year)		
Projected Completion Date (month/year)	2017	2017
If enrolled at a US university, will Trainee be a "Participant Trainee" as defined by USAID?	N/A	N/A
Training status	Completed	Completed

	Student 1	Student 2
Name	Ocran Chengula	Ezekiel Swema
Citizenship	Tanzania	Tanzania
Gender	Male	Male
HC Institution to Benefit from Training	Sokoine University of Agriculture	Sokoine University of Agriculture
Training Institution	Sokoine University of Agriculture	Sokoine University of Agriculture
Supervising LILPI	Fredy T. M. Kilima	Fredy T. M. Kilima
Degree Program for training	M.Sc.	M.Sc.
Field or Discipline	Agric. Econ.	Agric. Econ.
Thesis Title/Research Area	Factors underlying commercialization of bean production among smallholder bean farmers in Tanzania	Common Beans Attributes and Consumer Preference in Dar Es Salaam, Tanzania
Estimated USAID funding for activity if not conducted in US: US$ for Instruction		
Estimated USAID funding for activity if not conducted in US: US$ for Participants		
Estimated USAID funding for activity if not conducted in US: US$ for Travel		
Estimated OTHER funding for activity if not conducted in US: US$ for Instruction		
Estimated OTHER funding for activity if not conducted in US: US$ for Participants		
Estimated OTHER funding for activity if not conducted in US: US$ for Travel		
Start Date (month/year)		
Projected Completion Date (month/year)	2017	2018
If enrolled at a US university, will Trainee be a "Participant Trainee" as defined by USAID?	N/A	N/A
Training status	Active	Active

	Student 1	**Student 2**
First and Other Names	Elizabeth Medard	Rameck Rwakalaza
Citizenship	Tanzania	Tanzania
Gender	Female	Female
Training Institution	Sokoine University of Agriculture	Sokoine University of Agriculture
HC Institution to Benefit from Training	Sokoine University of Agriculture	Sokoine University of Agriculture
Supervising LIL PI	Fredy T. M. Kilima	Fredy T. M. Kilima
Degree Program for training	M.Sc.	M.Sc.
Field or Discipline	Agric. Econ.	Agric. Econ.
Thesis Title/Research Area	Factors Underlying Beans' Consumption Decisions in Dar Es Salaam Tanzania	Quadratic Almost Ideal Demand System For Common Beans Demand in Dar Es Salaam, Tanzania
Estimated USAID funding for activity if not conducted in US: US$ for Instruction		
Estimated USAID funding for activity if not conducted in US: US$ for Participants		
Estimated USAID funding for activity if not conducted in US: US$ for Travel		
Estimated OTHER funding for activity if not conducted in US: US$ for Instruction		
Estimated OTHER funding for activity if not conducted in US: US$ for Participants		
Estimated OTHER funding for activity if not conducted in US: US$ for Travel		
Start Date (month/year)		
Projected Completion Date (month/year)	2018	2018
If enrolled at a US university, will Trainee be a "Participant Trainee" as defined by USAID?	N/A	N/A
Training status	Active	Active

	Student 1	Student 2
Name	Jackson Jaccob	Mabvuto Zulu
Citizenship	Tanzania	Zambian
Gender	Male	Male
HC Institution to Benefit from Training	Sokoine University of Agriculture	The University of Zambia
Training Institution	Sokoine University of Agriculture	The University of Zambia
Supervising LIL PI	Fredy T. M. Kilima	Gelson Tembo
Degree Program for training	M.Sc.	Master of Science
Field or Discipline	Agric. Econ.	Agricultural Economics
Thesis Title/Research Area	Drivers of Beans' Consumers Choice in Tanzania	Consumer Preferences For Common Beans In Lusaka, Zambia. A Stated Preference Approach
Estimated USAID funding for activity if not conducted in US: US$ for Instruction		0
Estimated USAID funding for activity if not conducted in US: US$ for Participants		0
Estimated USAID funding for activity if not conducted in US: US$ for Travel		0
Estimated OTHER funding for activity if not conducted in US: US$ for Instruction		0
Estimated OTHER funding for activity if not conducted in US: US$ for Participants		0
Estimated OTHER funding for activity if not conducted in US: US$ for Travel		0
Start Date (month/year)		September 2015
Projected Completion Date (month/year)	2018	2018
If enrolled at a US university, will Trainee be a “Participant Trainee” as defined by USAID?	N/A	N/A
Training status	Active	Active

	Student 1	Student 2
Name	Isabel Sakala	Nandi Nomsa Jama
Citizenship	Zambian	Zambian
Gender	Female	Male
HC Institution to Benefit from Training	The University of Zambia	The University of Zambia
Training Institution	The University of Zambia	The University of Zambia
Supervising LIL PI	Gelson Tembo	Gelson Tembo
Degree Program for training	Master of Science	Master of Science
Field or Discipline	Agricultural Economics	Agricultural Economics
Thesis Title/Research Area	Consumer Choices and Consumption of Dry Common Beans in Zambia: A Double Hurdle Approach	A Quadratic Almost Ideal Demand System Estimation For Common Beans in Lusaka
Estimated USAID funding for activity if not conducted in US: US$ for Instruction	0	0
Estimated USAID funding for activity if not conducted in US: US$ for Participants	0	0
Estimated USAID funding for activity if not conducted in US: US$ for Travel	0	0
Estimated OTHER funding for activity if not conducted in US: US$ for Instruction	0	0
Estimated OTHER funding for activity if not conducted in US: US$ for Participants	0	0
Estimated OTHER funding for activity if not conducted in US: US$ for Travel	0	0
Start Date (month/year)	June 2016	June 2016
Projected Completion Date (month/year)	February 2018	February 2018
If enrolled at a US university, will Trainee be a "Participant Trainee" as defined by USAID?	N/A	N/A
Training status	Active	Active

	Student 1	**Student 2**
Name	Ednah Kasanda	Austin Mbamba
Citizenship	Zambian	Malawian
Gender	Female	Male
HC Institution to Benefit from Training		
Training Institution	Kansas State University	Kansas State University
Supervising LIL PI	Vincent Amanor-Boadu	Vincent Amanor-Boadu
Degree Program for training	Master of Agribusiness	Master of Agribusiness
Field or Discipline	Agribusiness	Agribusiness
Thesis Title/Research Area	Gender and Decision Making in Agriculture: A Case Study of Groundnuts Farmers in Zambia	Factors influencing the intensification of bean consumption in Malawi
Estimated USAID funding for activity if not conducted in US: US$ for Instruction		
Estimated USAID funding for activity if not conducted in US: US$ for Participants		
Estimated USAID funding for activity if not conducted in US: US$ for Travel		
Estimated OTHER funding for activity if not conducted in US: US$ for Instruction		
Estimated OTHER funding for activity if not conducted in US: US$ for Participants		
Estimated OTHER funding for activity if not conducted in US: US$ for Travel		
Start Date (month/year)	January 2015	Oct 2016
Projected Completion Date (month/year)	June 2017	May 2018
If enrolled at a US university, will Trainee be a "Participant Trainee" as defined by USAID?	N/A	N/A
Training status	Completed	Active

	Student 1
Name	Marvin Mbaso
Citizenship	Malawian
Gender	Male
HC Institution to Benefit from Training	
Training Institution	Kansas State University
Supervising LIL PI	Vincent Amanor-Boadu
Degree Program for training	Master of Agribusiness
Field or Discipline	Agribusiness
Thesis Title/Research Area	Socio-economic determinants of the position of beans in Malawian diets
Estimated USAID funding for activity if not conducted in US: US$ for Instruction	
Estimated USAID funding for activity if not conducted in US: US$ for Participants	
Estimated USAID funding for activity if not conducted in US: US$ for Travel	
Estimated OTHER funding for activity if not conducted in US: US$ for Instruction	
Estimated OTHER funding for activity if not conducted in US: US$ for Participants	
Estimated OTHER funding for activity if not conducted in US: US$ for Travel	
Start Date (month/year)	Jan 2016
Projected Completion Date (month/year)	May 2018
If enrolled at a US university, will Trainee be a "Participant Trainee" as defined by USAID?	N/A
Training status	Active

VII. Achievement of Gender Equity Goals

We have consciously endeavored on attaining gender equity in our activities. Five of our 15 graduate students supported by the program are females. Overall, 15 female graduate student and 14 male graduate students have been trained under this program. Approximately 500 of the more than 1,250 participants in our industry engagement and capacity building programs are females. In total, 345 people attended the six strategic alliance workshops in Zambia and Malawi with 112 (32 percent) of them being women.

VIII. Implementation of Data Management Plan

Currently the datasets from the three consumer surveys are being formatted in a software independent platform and the three codebooks are being prepared. The datasets and the cookbooks are expected to be uploaded to USAID Development Data Library by December 2017.

IX. Scholarly Accomplishments

V. Amanor-Boadu and K. Ross. 2017. "On the Role of Food Hierarchies on Consumption Choices: The Case of Legumes." *In progress. Target journal: Food Policy.*

V. Amanor-Boadu and R. Armah. 2017. "A System Dynamics Approach to Legume Consumption and Production in Select Markets: 2020-2035." *In progress. Target journal: International Journal on Food System Dynamics*.

V. Amanor-Boadu. 2017. Framing the Vision: Beans for Health and Wealth. National Conference Beans for Health and Wealth. Lilongwe, Malawi and Lusaka, Zambia.

V. Amanor-Boadu. 2017. Sharpening the Vision: Beans for Health and Wealth. National Conference Beans for Health and Wealth. Lilongwe, Malawi and Lusaka, Zambia.

V. Amanor-Boadu and K. Ross. 2017. Exploiting Food Hierarchies in Enhancing the Legume Industry's Competitiveness. National Conference Beans for Health and Wealth. Lilongwe, Malawi and Lusaka, Zambia.

R. Armah and V. Amanor-Boadu. 2017 Towards 2050: Projecting legume consumption and production under alternative socioeconomic and resource conditions. The Feed the Future Legume Innovation Lab, Grain Legume Research Conference. Ouagadougou, Burkina Faso, Aug. 12-18, 2017.

D. T. Banda, L. Mapemba, V. Amanor-Boadu, K. Ross and K. Machira. 2017. Effect of Interaction of Common Bean Attributes on Consumer Choice of Bean Varieties in Lilongwe District. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

D. T. Banda, K. Ross, V. Amanor-Boadu, and L. Mapemba. 2017. Effect of Interaction of Attributes that Influence Consumer Choice of Bean Varieties in Lilongwe City, Poster presented at the Legume Innovation Lab Global Conference, Ouagadougou, Burkina Faso, Aug. 13-18, 2017.

E. Chishimba, G. Tembo, V. Amanor-Boadu and M. Mwiinga. 2017. Factors Affecting Bean Profitability among Bean Traders in Zambia. Poster presented at the Legume Innovation Lab Global Conference, Ouagadougou, Burkina Faso, Aug. 13-18, 2017.

D. Chisusu. 2017. Contribution of Common Beans to Household Dietary Diversity and Calorie Consumption in Malawi. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

M. Chitete, H. Phiri, L. Mapemba, V. Amanor -Boadu, and J. Dzanja. 2017. Analysis of Structure, Conduct and Performance of Beans Marketing in Malawi: A Case Study of Lilongwe District. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

E. Kasanda. 2017. Gender and decision-making in agriculture: A case study of groundnuts farmers in Zambia. Master of Agribusiness Thesis. Kansas State University. Manhatan, Kansas. Available at https://krex.k-state.edu/dspace/handle/2097/35785.

E. Kenamu, L. D. Mapemba, K. Ross and V. Amanor-Boadu. 2017. Household Common Beans Consumption Behaviour in Urban Malawi: Empirical Evidence from Lilongwe City. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

E. Kenamu, L. D. Mapemba, V. Amanor-Boadu and K. Ross. 2017. Joint Consumption of Multiple Common Bean Varieties in Lilongwe City, Malawi, Poster presented at the Legume Innovation Lab Global Conference, Ouagadougou, Burkina Faso, Aug. 13-18, 2017.

P. Kotchofa and K. Ross. 2016. "Factors influencing beans consumption in Sub-Saharan Africa: Case of the Urban Consumer in Zambia." Missouri Valley Economics Association Conference, St. Louis, MO.

P. Kotchofa, K. Ross, V. Amanor-Boadu and Y. Zereyesus. Expenditure and Price Elasticities of Demand for Legumes in Northern Ghana, Poster presented at the Legume Innovation Lab Global Conference, Ouagadougou, Burkina Faso, Aug. 13-18, 2017.

Y. Lifeyo. 2017. Market Participation of Smallholder Common Bean Producers in Malawi. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

L. Mapemba, E. Kenamu and M. Mumba. 2017. Legume Value Chain Analysis of Demand and Supply in Malawi. Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

W. Msukwa. 2017. Household Demand for Common Beans in Lilongwe District of Malawi. Master of Science in Agricultural and Applied Economics Thesis, Lilongwe University of Agricultural and Natural Sources. Lilongwe, Malawi.

W. Msukwa, J. Mangisoni and L. Mapemba. 2017. Household Demand for Common Beans in Lilongwe District of Malawi. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

N. Moyo. 2016. Situational Analysis of Common Bean Production, Marketing and Consumption in Malawi. Master of Science in Agribusiness Thesis, Lilongwe University of Agricultural and Natural Sources. Lilongwe, Malawi.

N. Moyo, V. Amanor-Boadu, K. Ross, L. Mapemba and J. Dzanja. 2016. The Common Bean Subsector in Malawi: Current and Future Outlook of Yield, Area and Overall Production. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

N. Moyo, L. Mapemba, V. Amanor-Boadu and K. Ross. 2017. Production and Marketing Constraints, Current Status and Future Outlook of Common Bean Sub-Sector in Malawi, Poster presented at the Legume Innovation Lab Global Conference, Ouagadougou, Burkina Faso, Aug. 13-18, 2017.

M. Mwiinga. 2017. Factors affecting bean consumption among Lusaka residents. The Feed the Future Legume Innovation Lab, Grain Legume Research Conference. Ouagadougou, Burkina Faso. Aug. 13-18, 2017.

E. Swema. 2017. Consumer Preference for Common Bean Attributes in Dar-Es-Salaam, Tanzania. Master of Science in Agricultural and Applied Economics Thesis, Sokoine University of Agriculture. Morogoro, Tanzania. *In progress.*

E. Swema, G. Mlay, F. Kilima, V. Amanor-Boadu and K. Ross. Consumers' Preferences for Common Beans' Attributes in Dar es Salaam, Tanzania. Poster presented at the Legume Innovation Lab Global Conference, Ouagadougou, Burkina Faso, Aug. 13-18, 2017.

M. Tumeo, L. Mapemba, V. Amanor-Boadu, K. Ross and A.-K. Edriss. 2016. Consumer Choice of Dry Common Beans in Malawi: Case of Lilongwe City. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

M. Mazunda, L. Mapemba, V. Amanor-Boadu Vincent and K. Ross. 2017. Consumer Choice of Dry Common Beans in Lilongwe City of Malawi, Poster presented at the Legume Innovation Lab Global Conference, Ouagadougou, Burkina Faso, Aug. 13-18, 2017.

W. Msukwa, L. Mapemba, V. Amanor-Boadu and K. Ross. 2017. Household Demand for Common Beans in Lilongwe District of Malawi: A Censored Regression Approach. Poster presented at the Legume Innovation Lab Global Conference, Ouagadougou, Burkina Faso, Aug. 13-18, 2017.

X. Achievement of Impact Pathway Action Plan

We has indicated in our impact pathway narrative that the project will focus on beans and cowpeas. It became apparent in our deliberations that cowpeas were not a major crop in the study area and that we would be better of focusing on beans. Therefore, we restricted our focus to beans. That clarification is the primary deviation from the original impact pathway presented.

Our research focused on identifying the position of beans in the food hierarchy in our host countries. This was important because it would indicate the potential hurdle that would have to be overcome in order to enhance bean consumption. In the initial reports, we found that beans were on lower rungs of the food hierarchy in all three countries. This was true regardless of consumer characteristics.

We developed reports on the bean industry situation in each country. The target of these reports was researchers interested in the bean and legume industry in our host countries and the southern Africa sub-region, policymakers and industry stakeholders. We have presented these reports in numerous venues and shared them with the target audience in the host countries. We also developed numerous policy briefs that have also been shared with the target audience. We also delivered several workshops and capacity building programs over the course of the project. We had indicated that we expected these reports to enhance performance of these target audiences by 30%. At this point, we are unable to confirm the impact. However, activity enhancements in Malawi and Zambia reported above would suggest that we might exceed this modest enhancement by 2025. For example, an industry group focused on enhancing consumption has been initiated in

Zambia and a producer association in Malawi has developed a special relationship with some traders to improve their value chain operations.

We indicated developing innovative business models for the different nodes in the bean value chain. The chains were short in all three countries, thus, we focused on facilitating business models at the producer and trader interfaces. Bean processing is lacking in all three countries. One processor with high profile operations in Zambia went into receivership not long after we started working with them and a new processor was just coming on line in southern Zambia. We initiated conversations with this new processor and helped the company's leadership appreciate the idiosyncrasies of the food industry given their non-food background. We envisage the possibility of some processors in the Malawi tobacco industry exploring potential opportunities in beans with the increasing exit pressure for tobacco industry stakeholders.

Our monitoring and evaluation of the business models we have contributed to developing will continue in the post-project era. We are doing this by maintaining our relationships with the stakeholders. We will collect performance information from producer associations, processors and traders over the next several years with the view to providing support and evaluating performance. The challenge we envisage is in changes in the personnel in these organizations and the potential loss of continuity given that we are hoping to sustain engagements over the next eight years.

Our outreach programs – conferences and workshops – have enhanced the public's awareness about beans for health and wealth in both Malawi and Zambia. We hope we can undertake a similar activity in Tanzania in the near future to accelerate consumption in that country since it has the highest potential to assume higher value product consumption because of the current position of beans in its food hierarchy. For example, in both Malawi and Zambia, our project organized the first national conference on beans. Local stakeholders have been impressed enough about its success they are planning to make these initiatives annual events for promoting bean consumption. The local stakeholder effort to undertake these events provides evidence that we have succeeded in creating an enabling environment to continue the achievements of this project.

ANNEXES

Annex 1. Tables, Figures, and Photos Cited in the Report

See the attached document for the scholarly accomplishments for FY2017.

Annex 2. Literature Cited

Sichilima, T., L. Mapemba, and G Tembo. (2016). Drivers of Dry Common Beans Trade in Lusaka, Zambia: A Trader's Perspective. Sustainable Agriculture Research.

Explanation for Not Achieving the Milestones (April 1, 2017)

Milestones	
Objective 1	
1.1 Policy Briefs - Consumption 1.2 Consumption Report 1.3 Report Rollout 1.4 Policy Briefs - Downstream Acts.	We are still looking to hire local support to help with the completion of these reports. Our Host Country PIs have indicated their commitment to helping with these reports; however, no output has been received so far.
1.5 Outreach Bean Contest	This activity has been removed from our FY2017 activities. Concepts from this activity were incorportated into the national conference in Malawi, which was held in March 2017.
Objective 2:	
2.1 Country Comparison -Production 2.2 Country Compar. -Downstream Acts.	We are still looking to hire local support to help with the completion of these reports. Our Host Country PIs have indicated their commitment to helping with these reports; however, no output has been received so far.
Objective 3:	
3.1 Plan Training Workshop	Achieved
3.2 Conduct Training Workshops	Achieved

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes

Report on the Achievement of "Milestones of Progress"
(For the Period: April 1, 2017 -- September 29, 2017)

This form should be completed by the U.S. Lead PI and submitted to the MO by September 29, 2017

Project Title: **S02.2 Enhancing Pulse Value-Chain Performance through Improved Understanding of Consumer Behavior and Decision-Marking**

	Abbreviated name of Institutions																	
	KSU			LUANR			SUA			UZ			Institution 5			Institution 6		
	Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved	
Milestones by Objectives	9/29/17	Y	N*	9/29/17	Y	N*	9/29/17	Y	N*	9/29/17	Y	N*	9/29/17	Y	N*	9/29/17	Y	N*
	(Tick mark the Yes or No column for identified milestones by institution)																	
Objective 1	**Identify and analyze the principal factors shaping legume consumption and their relative positions in consumers' food rankings in the selected countries.**																	
1.1 Policy Briefs - Consumption	0			0			0			0			0			0		
1.2 Consumption Report	0			0			0			0			0			0		
1.3 Report Rollout	0			0			0			0			0			0		
1.4 Policy Briefs - Downstream Acts.	√	X		√	X		√	X		√	X		0			0		
1.5 Outreach Bean Contest	0			0			0			0			0			0		
Objective 2:	**Conduct situation analyses for legume production and marketing/distribution systems with a view to identifying the nature and extent of the gaps in their value chains.**																	
2.1 Country Comparison -Production	0			0			0			0			0			0		
2.2 Country Compar. -Downstream Acts.	0			0			0			0			0			0		
2.3	0			0			0			0			0			0		
2.4	0			0			0			0			0			0		
2.5	0			0			0			0			0			0		
Objective 3:	**Implement formal and informal capacity building initiatives to address identified gaps and support value chain management capacity across the legume industry in the foc**																	
3.1 Plan Training Workshop	0			0			0			0			0			0		
3.2 Conduct Training Workshops	√	X		√	X		√	X		√	X		0			0		
3.3 Education Initiatives	√	X		√	X		√	X		√	X		0			0		
3.4	0			0			0			0			0			0		
3.5	0			0			0			0			0			0		
Objective 4:	**write objective here**																	
4.1	0			0			0			0			0			0		
4.2	0			0			0			0			0			0		
4.3	0			0			0			0			0			0		
4.4	0			0			0			0			0			0		
4.5	0			0			0			0			0			0		
Name of the PI reporting on milestones by institution	V. Amanor-Boadu			L. Mapemba			F. Kilima			G. Tembo			PI name			PI name		

Name of the U.S. Lead PI submitting this report to the MO V. Amanor-Boadu

Signature

Date

* *Please provide an explanation for not achieving the milestones on a separate sheet.*

XI. Legumes and Growth (SO3.1)

Lead U.S. Principal Investigator and University:
Mark Manary MD, Helene Roberson Professor of Pediatrics
Washington University School of Medicine in St. Louis

Collaborating Host Country and U.S. PIs and Institutions:
Ken Maleta MBBS PhD, Professor in Community Health, University of Malawi College of Medicine
Chrissie Thakwalakwa PhD, Lecturer in Community Health, University of Malawi College of Medicine
Indi Trehan MD, Associate Professor of Pediatrics, Washington University School of Medicine in St. Louis

I. Abstract of Research and Capacity Strengthening Achievements

(A succinct narrative on the technical progress of the project, including key research and capacity strengthening achievements and outcomes, during the FY 2017 performance and report period. 1200 character limit.)
In FY17, complete sample collection for Study 2 was accomplished. Samples were sent to the University of California, San Diego, for sequencing and analysis. The local team implementing the clinical trial continued ongoing training in the principles of "Good Clinical Practice" until the trial was completed. Two Malawian PhD students enrolled at the University of Malawi-College of Medicine furthered their knowledge and education by learning extraction and sequencing techniques in the laboratory at Washington University and by attending classes and other training/seminars during this fiscal year. Three articles with results were published in American Society for Nutrition journals.

II. Project Problem Statement and Justification

(*Present a <u>concise</u> problem statement and justification for the research and capacity strengthening activities carried out in this project. Please* ***do not provide a cut-and-pasted version of the project problem statement*** *from the Technical Application. 2000 character limit.)*
Successful interventions to help prevent children from becoming malnourished and achieve their full growth potential remain lacking. Environmental enteric dysfunction (EED), a pervasive chronic subclinical gut inflammatory condition, places rural children at high risk for malabsorption, stunting, and acute malnutrition. Minimizing EED is an essential step in improving the survival and growth of at-risk children. EED is characterized by T-cell infiltration of the intestinal mucosa leading to a chronic inflammatory state with increased intestinal permeability, translocation of microbes, nutrient malabsorption, poor weight gain, stunted physical and cognitive development, frequent enteric infections, and decreased response to enteric vaccines. EED often begins to develop shortly after the transition away from exclusive breastfeeding and increases progressively during the first several years of life, a high-risk period marked by mixed feeding with complementary foods to the complete reliance on adult foods for

sustenance. In traditional sub-Saharan African societies, complementary foods are dominated by protein-poor and micronutrient-poor starches such as maize, cassava, and sorghum. Alternative, yet culturally acceptable, complementary foods that could provide a better and more palatable balance of nutrients would potentially decrease in EED and improve growth amongst these at-risk children. In this study, we tested two different legume foods as complementary food products, given that their protein content is significantly higher than cereals, and they are rich in dietary fiber, starch, minerals, vitamins, and antioxidants. The active engagement of several Malawian graduate students as part of the capacity-building activities is essential to this work, as their local insights and knowledge of food systems and cultural feeding practices will help guide the optimal development and implementation of these

III. Technical Research Progress

(*Describe the research activities (research methods, studies conducted, analyses completed, and significant findings) completed under each objective during the FY 2017 reporting period. Present sufficient detail so that the reviewers will understand and have confidence that the research was carried out in a manner that meets high scientific standards. Briefly discuss primary results, findings, and/or technological achievements that give evidence of technical progress toward objectives. Please be reminded to highlight significant outputs that have potential for impact.*)

Objective 1: *Enrollment, intervention delivery and specimen collection in infants with a dietary legume.*

This objective began in July 2015 after several months preparation and completed in December 2016. Two legume interventions were tested, common bean and cowpea. Children were enrolled as they turned 6 mo of age and participated until they were 12mo of age. Four hundred children were assessed for eligibility, 355 randomized to one of 3 interventions; cowpea, common bean or control. Children were followed every 6 weeks, assessed for anthropometric status and compliance with consumption of the legume supplement. Of the 291 children that completed the entire 6 mo of participation, daily compliance was high, mothers reported giving the legume on 98% of the study days. Among those children that did not complete the participation, the most common reason was development of acute malnutrition in 42/64 children, which required therapy with supplementary or therapeutic feeding. Over 2000 fecal specimens were collected, snap frozen in liquid nitrogen and delivered to the analyzing labs. Three dual sugar permeability tests were done; at 6mo, 9mo and 12mo of age. Almost all fecal samples were sequenced for 16s rDNA and metagenomics, as well as having fecal metabolites measured. The findings are discussed under the achievement section.

Objective 2: *Recipe Development*

The LUANAR graduate students developed food recipes using cowpeas and common beans in accordance with WHO specification earlier in the research project. The candidate recipes underwent acceptability testing in Malawian infants with the support of the Malawi College of Medicine. Simple roasted and milled cowpea and common bean were chosen as the intervention on the basis of infant acceptability, safety and practicality. The dosages of legumes given daily were 80 kcal/d when 6-9 mo old, 120 kcal/d when 10-12 mo, 155kcal/d when12-23 mo and 200kcal/d when 24-35 mo.

Children avidly took these legume supplements as powder poured on top of their cereal porridge. Mothers offered no complaints regarding the supplements.

Objective 3: *Enrollment, intervention delivery and specimen collection in young children with a dietary legume.*
This objective began in July 2015 after several months preparation and completed in December 2016. Two legume interventions were tested, common bean and cowpea. Children were enrolled during the ages of 12-24 mo and participated for 12 subsequent months. Four hundred thirty-five children were assessed for eligibility, 383 randomized to one of 3 interventions; cowpea, common bean or control. Children were followed every 6 weeks, assessed for anthropometric status and compliance with consumption of the legume supplement. Of the 329 children that completed the entire 12 mo of participation, daily compliance was high, mothers reported giving the legume on 98% of the study days. Among those children that did not complete the participation, the most common reason was development of acute malnutrition in 35/54 children, which required therapy with supplementary or therapeutic feeding. Almost 4000 fecal specimens were collected, snap frozen in liquid nitrogen and delivered to the analyzing labs. Five dual sugar permeability tests were done: upon enrolment, after 3mo, 6mo, 9mo and 12mo of participation. A representative group of fecal samples were sequenced for 16s rDNA and metagenomics, as well as having fecal metabolites measured. The findings are discussed under the achievement section.

Objective 4: *Increase the capacity, effectiveness and sustainability of agriculture research institutions in Malawi.*
The PI and the research team continued to promote sustainable research through relationships with the University of Malawi College of Medicine and with colleagues at LUANAR. In addition to the training of four graduate students, a junior faculty member, Chrissie Thakwalakwa at the College of Medicine, continued to be supported by this project and provided overall supervision of the field studies. The Agriculture Department at LUANAR was engaged in developing the formulations and recipes using cowpeas and common beans, and the Washington University team trained two student LUANAR food scientists on the development processes used in the Washington University food science lab. The two PhD students recruited at the Malawi College of Medicine attended classes, learned lab techniques and attended other seminars/lectures/conferences to enhance their knowledge base at Washington University in St. Louis, they then returned to Malawi to utilize these new skills to complete their educational training.

IV. Major Achievements

(*Present a **list of significant research achievements and/or technical advances resulting from project activities during the FY 2017 performance period**. The description of each achievement need not be more than three sentences long. Quantitative information on or a technical description of the research achievement would be appreciated because it adds credibility to the importance of the achievement.*)

1. We proved that cowpea supplementation improves linear growth in 6-12 mo Malawian children

2. We proved that common bean supplementation improves gut health in 12-36 mo Malawian children
3. 100% sample collection in Study 2, requiring a large amount of effort and resources, including collaboration in the districts where the studies were conducted.
4. Two Malawian PhD students successfully completed classes at Washington University and were taught ddPCR and other lab techniques.
5. Analyzed all data from the field including anthropometic data and its relationship to L:M showing the change in Environmental Enteropathy.
6. 4048 fecal samples were sequenced and characterized to determine the bacterial and metabolic signature for growth and gut health.
7. Three articles have been published and 4 more are in preparation describing this work.

V. Research Capacity Strengthening

(*Describe how collaborative research activities supported by the project during FY 2017 have contributed to the strengthening of institutional capacity to carry out multidisciplinary research on grain legumes and to solve the problems facing the legume sectors in host countries and regions. Appropriate capacity strengthening items to present in this section include research equipment procured (>$5,000), laboratory and analytical facilities developed, participation in professional meetings or other networking activities, etc. Please also identify in this section the activities completed and equipment procured during the past fiscal year with supplemental Institutional Capacity Strengthening funds received by host country institutions in the respective project.)*

The PI and the research team continue to promote sustainable research through relationships with the Malawi College of Medicine and with colleagues at LUANAR. The training provided to the four Malawian graduate students continued and helped them to develop into investigators able to continue research on childhood malnutrition, especially in the use of grain legumes. Chrissie Thakwalakwa of the College of Medicine, with support from Drs. Manary, Trehan, and Maleta, continued to supervise the field team, honing and improving her skills in conducting large collaborative clinical trials aimed at improving the nutritional status of impoverished rural children. The Agriculture Department at LUANAR was engaged in developing the formulations and recipes using cowpeas and common beans, and the Washington University team trained two student LUANAR food scientists on the development processes used in the Washington University food science lab. One of these students continues to be engaged in by supervising production and quality control of the flours using the food science and safety knowledge she obtained as part of her training. The two Malawian PhD students attended classes at Washington University that are not offered at the University of Malawi increasing their research knowledge base. These students have also been trained in ddPCR lab techniques utilized in Dr. Manary's lab at Washington University and attended a Scientific Nutrition Conference in Chicago, Illinois.

VI. Human Resource and Institution Capacity Strengthening

(*This section is a compilation of short-term and long-term degree training activities completed by the project during the performance period. This section is intended to be* *independent of research capacity strengthening activities described in the previous section.)*

12. **Short-Term Training**

    (*Provide the following information for each short-term training activity completed. If a training was repeated in several places, each training must have a separate entry. Short term training is defined as a minimum of two consecutive class days or more in duration, or 16 contact hours or more scheduled intermittently.*)

    Short-Term Training: Staff Field Training

    a. *Purpose of Training:* Study research nurses, drivers, research assistants and staff received training in study guidelines, anthropometric data collection skills, biological sample collection methods and community engagement. Having a knowledgeable and capable staff is vital to conducting research.
    b. *Type of Training:* Field Training for research activities
    c. *Country Benefiting:* Malawi
    d. *Location and dates of training:* Malawi, 2016
    e. *Number receiving training (by gender):* 6 female nurses, 4 male drivers, 15 village health workers (11 male, 4 female)
    f. *Home institution(s) (if applicable):* Nurses and drivers are from the University of Malawi College of Medicine; village health workers are employed by the Ministry of Health
    g. *Institution providing training or mechanism:* University of Malawi College of Medicine

    Short-Term Training: Malawi PhD Visiting Researchers

    a. *Purpose of Training:* Visiting Malawian researchers attending conference focused on areas of anatomy, biochemistry and molecular biology, investigative pathology, nutrition, pharmacology and physiology allowing access to the latest research impacting life sciences.
    b. *Type of Training:* Experimental Biology Meeting
    c. *Country Benefiting:* Malawi
    d. *Location and dates of training:* Chicago, IL USA, April 22-26, 2017
    e. *Number receiving training (by gender):* 2 PhD candidates (1 male and 1 female)
    f. *Home institution(s) (if applicable):* University of Malawi College of Medicine
    g. *Institution providing training or mechanism:* American Association of Anatomists, American Physiological Society, American Society for Biochemistry and Molecular Biology, American Society for Investigative Pathology, ASPECT

Short-Term Training: Malawi PhD Visiting Researchers

a. *Purpose of Training:* Visiting Malawian researchers training in Good Clinical Practices and basic Human Subject Training
b. *Type of Training:* Good Clinical Practices, HRPO-Basic Human Subject Education for BioMed IRB members, CITI training, HIPPA Privacy and Information Security

c. *Country Benefiting:* Malawi
d. *Location and dates of training:* St. Louis, MO August 28th - September 1st
e. *Number receiving training (by gender):* 2 PhD candidates (1 male and 1 female)
f. *Home institution(s) (if applicable):* University of Malawi College of Medicine
g. *Institution providing training or mechanism:* Washington University in St. Louis

1. Degree Training

lxxi. *Name of trainee:* Lucy Bollinger
lxxii. *Country of Citizenship:* USA
lxxiii. *Gender:* Female
lxxiv. *Host Country Institution Benefitting from Training:* University of Malawi College of Medicine
lxxv. *Institution providing training:* Washington University
lxxvi. *Supervising CRSP PI*: Mark Manary and Indi Trehan
lxxvii. *Degree Program:* Masters
lxxviii. *Field or Discipline:* Biological Sciences
lxxix. Research Project Title (if applicable)
lxxx. *Start Date:* May 2015
lxxxi. *Projected Completion Date*: May 2016
lxxxii. *Is trainee a USAID Participant Trainee and registered on TraiNet?* No
lxxxiii. *Training status (Active, Completed, Pending, Discontinued, or Delayed):* Completed

13. Degree Training

i. *Name of trainee:* William Cheng
ii. *Country of Citizenship*: USA
iii. *Gender:* Male
iv. *Host Country Institution Benefitting from Training:* Washington University
v. *Institution providing training:* Washington University
vi. *Supervising CRSP PI:* Mark Manary and Indi Trehan
vii. *Degree Program:* Masters
viii. *Field or Discipline*: Biological Sciences
ix. Research Project Title (if applicable)
x. *Start Date:* May 2016
xi. *Projected Completion Date:* May 2017
xii. *Is trainee a USAID Participant Trainee and registered on TraiNet?* No
xiii. *Training status (Active, Completed, Pending, Discontinued, or Delayed):* Active

14. Degree Training

i. Name of trainee: Oscar Divala
ii. Country of Citizenship: Malawi
iii. Gender: Male

iv. *Host Country Institution Benefitting from Training:* University of Malawi College of Medicine
v. *Institution providing training:* University of Malawi College of Medicine
vi. *Supervising CRSP PI:* Mark Manary, Ken Maleta, Indi Trehan
vii. *Degree Program:* PhD
viii. *Field or Discipline:* Epidemiology
ix. *Research Project Title:* N/A
x. *Start Date*: August 2015
xi. *Projected Completion Date:* June 2018
xii. *Is trainee a USAID Participant Trainee and registered on TraiNet?:* No
xiii. *Training status (Active, completed, pending, discontinued or delayed):* Active

15. **Degree Training**

i. *Name of trainee:* Yankho Kaimila
ii. *Country of Citizenship:* Malawi
iii. *Gender:* Female
iv. *Host Country Institution Benefitting from Training:* University of Malawi College of Medicine
v. *Institution providing training:* University of Malawi College of Medicine
vi. *Supervising CRSP PI:* Ken Maleta
vii. *Degree Program:* PhD
viii. *Field or Discipline:* Epidemiology
ix. *Research Project Title:* N/A
x. *Start Date*: August 2015
xi. *Projected Completion Date:* June 2018
xii. *Is trainee a USAID Participant Trainee and registered on TraiNet?:* No
xiii. *Training status (Active, completed, pending, discontinued or delayed):* Active

5. Degree Training

i. *Name of trainee:* Chrissie Thakwalakwa
ii. *Country of Citizenship:* Malawi
iii. *Gender:* Female
iv. *Host Country Institution Benefitting from Training:* University of Malawi College of Medicine
v. *Institution providing training:* Tampere University in Finland
vi. *Supervising CRSP PI:* Ken Maleta
vii. *Degree Program:* PhD
viii. *Field or Discipline:* Community Health
ix. *Research Project Title:* N/A
x. *Start Date*: August 2015
xi. *Projected Completion Date:* July 2017

xii. *Is trainee a USAID Participant Trainee and registered on TraiNet?:* No
xiii. *Training status (Active, completed, pending, discontinued or delayed):* Active

6. Degree Training

i. *Name of trainee:* Theresa Ngoma
ii. *Country of Citizenship:* Malawi
iii. *Gender:* Female
iv. *Host Country Institution Benefitting from Training:* The Lilongwe University of Agriculture and Natural Resources (LUNAR)
v. *Institution providing training:* LUNAR
vi. *Supervising CRSP PI:* Mark Manary, Indi Trehan, Ken Maleta
vii. *Degree Program:* Masters
viii. *Field or Discipline:* Food Science and Technology
ix. *Research Project Title:* N/A
x. *Start Date:* January 2015
xi. *Projected Completion Date:* December 2015
xii. *Is trainee a USAID Participant Trainee and registered on TraiNet?* No
xiii. *Training status (Active, completed, pending, discontinued or delayed):* Active

7. Degree Training

i. *Name of trainee:* Ulemu Chimimba
ii. *Country of Citizenship:* Malawi
iii. *Gender:* Female
iv. *Host Country Institution Benefitting from Training:* LUNAR
v. *Institution providing training:* LUNAR
vi. *Supervising CRSP PI:* Mark Manary, Indi Trehan, Ken Maleta
vii. *Degree Program:* Masters
viii. *Field or Discipline:* Food Science and Technology
ix. *Research Project Title:* N/A
x. *Start Date:* January 2015
xi. *Projected Completion Date:* December 2015
xii. *Is trainee a USAID Participant Trainee and registered on TraiNet?:* No
xiii. *Training status (Active, completed, pending, discontinued or delayed):* Complete

VII. Achievement of Gender Equity Goals

(*Describe progress in achieving gender equity goals set for the project during the performance period. This includes training, involvement in project activities, and research approaches.*)

Beneficial findings and knowledge gained from these studies will benefit both women and men in these societies, including parents and children. Farming work is generally carried out by both men and women in this agrarian culture, so this will benefit both genders. Improvements in child health are most likely to benefit women in Malawi, as they have the primary role in childrearing. Health improvements that lead to improved survival and intellectual development of girls will also likely translate into improved school performance and capacity for careers. Demonstrating achievement of such goals is beyond the scope of the current project.

In terms of training future scientists, all but one of our Malawian graduate students is female. One of our American graduate students is female. One of our non-degree American students is female.

Particular care was extended to women for inclusion in the Food Safety training course, with approximately 46% of attendees being female.

VIII. Implementation of Data Management Plan

(*Describe efforts to implement of project's Data Management Plan, including a summary of data sets that have been submitted to Open Data Access sites, including USAID DDL. Indicate your Open Data Access sites for future submissions as well.*)

At this time data sets have not been submitted to the USAID DDL, however, they will be submitted prior to November 30th.

IX. Scholarly Accomplishments

(*Identify all **publications**, theses and/or dissertations, presentations, professional recognitions, awards, patents, and Plant Variety Protection Certificates that evidence scholarly accomplishments by U.S. and Host Country scientists as well as degree trainees during the performance period. Please send electronic copies of publications to the MO for sharing with USAID and include URL or DOI information where available.)*

1. Borresen, et al. "The nutrient and metabolite profile of three complementary legume foods with potential to improve gut health in rural Malawian children". Curr Dev Nutr 2017;1:e001610; DOI: 10.3945/cdn.117.001610
2. Stephenson, et al. "Complementary feeding with cowpea reduces growth faltering in rural Malawian infants: a randomized, blinded, controlled clinical trial". Am J Clin Nutr (accepted).
3. Agapova, et al. "Additional common bean in the diet of Malawian children does not affect linear growth, but reduces intestinal permeability". J Nutr (accepted)
4. Ngoma, et al. "Effect of cowpea flour processing on the chemical properies and acceptability of a novel cowpea blended maize porridge". PLoS ONE (under review).

X. Achievement of Impact Pathway Action Plan

(At the project planning and workplan development stage, each project team prepared an Impact Pathway identifying major research outputs, users of these outputs, a vision of success, and necessary steps to achieve the vision of success. In the Impact Pathway worksheet, your project also identified strategies and an action plan to be undertaken by the project team over the 4.5 year life of the project to translate the outputs into outcomes. Please provide an update on your team's efforts in implementing the action plan and progress towards achieving the 'vision of success' as laid out in the Impact

Pathway strategy. Discuss any constraints encountered and steps taken to overcome them.)
We remain on track with the Impact Pathway developed during the project planning and workplan stage. Both Goal 1 (capacity building) and Goal 2 (clinical trial decreasing stunting and EED) are being carried out as planned. The measurements of success (Steps 3 and 4) are still several years away from completion, as originally planned.

ANNEXES

Annex 1. Tables, Figures, and Photos Cited in the Report

Annex 2. Literature Cited

(*List all literature cited in the body of the technical progress report in full bibliographic form*.)

Feed the Future Innovation Lab for Collaborative Researchon Grain Legumes
Report on the Achievement of "Milestones of Progress"
(For the Period: October 1, 2016-- March 31, 2017)

This form should be completed by the U.S. Lead PI and submitted to the MO by April 1, 2017

Project Title: Project Code and Title: S03.1 Legumes and growth

	Abbreviated name of institutions								
	Washington Uni S Medicine			Malawi College Medicine			Colorado State		
	Target	Achieved		Target	Achieved		Target	Achieved	
Milestones by Objectives	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *
	(Tick mark the Yes or No column for identified milestones by institution)								
Objective 1: Completion of intervention delivery and specimen collection in infant project									
1.1 Specimen collection on 75% of participants complete	1	1		1	1		0		
1.2 Specimen collection on 100% of participants complete	1	1		1	1		0		
1.3 Samples sent for microbiota analyses	1	1		0			0		
1.4 Samples sent for microbiome analyses	1	1		0			0		
1.5 Samples sent for metabolome analyses	1	1		0			0		
Objective 2: Toxin and nutrient assessment of legume complementary foods									
2.1 Compositional analyses of legume foods	1	1		0			1	1	
2.2 Toxin analyses of legume foods	1	1		0			1	1	
2.3 Metabolite analyses of legume foods	1	1		0			1	1	
Objective 3: Completion of intervention delivery and specimen collection in young child project									
3.1 Specimen collection on 75% of participants complete	1	1		1	1		0		
3.2 Specimen collection on 100% of participants complete	1	1		1	1		0		
3.3 Samples sent for microbiota analyses	1	1		0			0		
3.4 Samples sent for microbiome analyses	1	1		0			0		
Objective 4: Collaboration with Malawi Research									
4.1 Malawian graduate students arrive in US	1	1		0			0		
4.2 Completion of first semester course work and laboratory t	1	1		0			0		
4.3 Completion of second semester course work and laborato	0			0			0		
4.4 Engagement activities with College of Medicine	0			1	1		0		
Name of the PI reporting on milestones by institution	Mark Manary			Ken Maleta			Elizabeth Ryan		
Name of the U.S. Lead PI submitting this Report to the MO	k Manary								

Signature

* *Please provide an explanation for not achieving the milestones on a separate sheet.*

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes
REVISED PERFORMANCE INDICATORS / TARGETS SPREADSHEET for FY 14, FY 15, FY16, and FY 17

Project Name: SO3.1

Institution 2 Name (University of Malawi School of Medicine

Indic. number	Output Indicators	FY 14 Target	FY 14 Revised	FY 14 Actual	FY 15 Target	FY 15 Revised	FY 15 Actual	FY 16 Target	FY 16 Revised	FY 16 Actual	FY 17 Target	FY 17 Revised	FY 17 Actual	FY18 Target	FY 18 Revised	FY 18 Actual
		(October 1, 2013 - September 30, 2014)			(October 1, 2014 - September 30, 2015)			(October 1, 2015 - September 30, 2016)			(October 1, 2016 - September 30, 2017)			(Oct 1, 2017 - Nov 30, 2017)		
1	4.5.2(6) Degree Training: Number of individuals who have received degree tra	0	0	0	6	0	5	4	4	4	0	0	3	2	0	0
	Numbers by Sex	0	0	0	3	0	4	2	3	3	2	0	3	2	0	0
	Number of women				3		4	2	3	3	2		2	1		
	Number of men				3		1	2	1	1	2		1	1		
	Numbers by New/Continuing	0	0	0	6	0	5	4	4	4	0	0	3	4	4	0
	New				6		5	0	0	0	0					
	Continuing				0			4	4	4	0	0	3	4	4	0
2	4.5.2(7) Short-term Training: Number of individuals who have received short-term training													0	0	0
	Numbers by Sex	0	0	0	6	0	7	6	5	15	6	0	15	0	0	0
	Number of women				6		5	6	5	10	6		10			
	Number of men				6		7	6	5	15	6		15			
	Numbers by Type of Individual	0	0	0	12	0	15	12	0	66	12	0	25	0	0	0
	Producers									7			0	0	0	0
	Number of women									4						
	Number of men									3						
	People in government				12		15	12		37	12		15	0	0	0
	Number of women									14			4			
	Number of men									23			11			
	People in private sector firms									7			10	0	0	0
	Number of women									3			6			
	Number of men									4			4			
	People in civil society									15			0	0	0	0
	Number of women									8						
	Number of men									7						
7	4.5.2(39) Number of new technologies or management practices in one of the following phases of development: (Phase I/II/III)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Phase 1: Number of new technologies or management practices under research as a result of USG assistance															
	Phase 2: Number of new technologies or management practices under field testing as a result of USG assistance															
	Phase 3: Number of new technologies or management practices made available for transfer as a result of USG assistance															

Notes:

These indicators are developed under the Feed the Future Monitoring System. Disaggregate where applicable. Just providing 'totals' will not be approved.

This table corresponds to the Feed the Future Performance Indicators data collection sheet under the FTFMS system. Where an indicator does not apply, leave it blank.

There is additional guidance on the USAID website: https://feedthefuture.gov/sites/default/files/resource/files/Feed_the_Future_Indicator_Handbook_Sept2016.pdf

XII. Impact Assessment of Dry Grain Pulses CRSP investments in research, institutional capacity building and technology dissemination for improved program effectiveness (SO4.1)

Lead U.S. Principal Investigator and University:
Mywish Maredia, Professor, International Development, Agricultural, Food and Resource Economics (AFRE), Michigan State University

Collaborating Host Country and U.S. PIs and Institutions:
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I. Abstract of Research and Capacity Strengthening Achievements

In this final year of the Legume Innovation Lab, several assessments and case studies focused on outputs, outcomes and impact of legume research were completed by this project in Burkina Faso, Uganda, Guatemala, Haiti, and Nicaragua. Results of these assessments have important implications for impact oriented legume research in developing countries. The baseline assessment in Guatemala confirmed that men and women farmers have slightly different preferences for varietal traits, but the ranking of different types of traits was the same. Overall, size and color of the bean, and productivity traits were the top two most important traits preferred by both men and women. The study in Uganda based on a nationally representative survey of households suggests consistent positive effects of legume rotation, intercropping, and other legume technologies on calorie and protein production per capita. This evidence points to the need to promote these practice where it is feasible for farmers to do so. Research studies on the theme of sustainable seed system were extended to two more countries this year--Burkina Faso and Nicaragua. The results of the willingness to pay experiments conducted in these two countries are consistent with the previous studies conducted in Tanzania and Ghana. Together this cohort of four studies indicate that quality seeds do perform better and farmers are able to perceive this performance difference and willing to pay a premium for quality seed. However, across all the countries studied, for a significant proportion of legume growing farmers the willingness to pay a premium for quality seed is much lower than the existing certified seed to grain price ratio. Current efforts to promote private sector led production and supply of certified seeds can potentially meet the seed needs of at most 30-35% of farmers. More research and discussion needs to happen to address the seed needs of a majority of farmers (two-thirds or more) whose WTP for quality seed is below the price at which certified seeds are sold in the market. The results of the farmer survey in Haiti point to the challenge of sustaining the use of improved varieties once they are disseminated to farmers through a systematic seed

dissemination efforts such as the BTD project. This is due to the fact that most farmers sell their harvest and don't save seeds for the next planting. Secondly, the bean varieties have no name recognition, which makes it difficult to track improved varieties disseminated through formal channels. In this circumstances, DNA fingerprinting offers the best approach for varietal identification and estimating varietal adoption.

II. Project Problem Statement and Justification

Impact assessment is essential for evaluating publicly-funded research programs and planning future research. Organizations that implement these programs should be accountable for showing results, demonstrating impacts, and assessing the cost-effectiveness of their implementation strategies. It is therefore essential to document outputs, outcomes and impacts of public investments in research for development (R4D) activities. Anecdotal data and qualitative information are important in communicating impact to policymakers and the public, but must be augmented with empirical data, and sound and rigorous analysis.

The proposed research contributes towards evidence-based rigorous ex ante and ex post assessments of outputs, outcomes and impacts with the goal of assisting the Legume Innovation Lab program and its Management Office (MO) to achieve two important goals--accountability and learning. Greater accountability (and strategic validation) is a prerequisite for continued financial support from USAID and better learning is crucial for improving the effectiveness of development projects and ensuring that the lessons from experience – both positive and negative – are heeded. Integrating this culture of 'impact assessment' in publicly funded programs such as the Legume Innovation Lab and generating knowledge outputs will ultimately help increase the overall impact of such investments.

III. Technical Research Progress

Objective 1. Provide technical leadership in the design, collection and analysis of data for strategic input and impact evaluation

1a. Analysis of baseline study in Guatemala

A baseline survey of more than 500 farm households from the five departments (Quiche, Huehuetenango, San Marcos, Chimaltenango and Quetzaltenango) of the Altiplano region of Guatemala was conducted in 2015 jointly with the SO1.A1 project team under their objective 'Genetic improvement of climbing black beans for the highlands of Central America.' The main objective of this survey was to study the constraints and opportunities for research to contribute to increased productivity of climbing beans in Guatemala. In FY 17, the data analysis was completed and a working paper has been developed for wider dissemination.

Main Results: This study is one of the first representative farm surveys of climbing bean growers in the *altiplano* region of Guatemala. The analysis of this data has helped gain a better understanding of farmer characteristics, bean production practices in the *milpa* system, varietal trait preferences, and the role of beans in household food consumption. The analysis contributes towards establishing priorities for the climbing bean breeding program targeted for increasing the productivity of the *milpa* system. It confirms the importance of beans in both the production and dietary systems of the indigenous people living in this region. More than 90% of farmers surveyed consider beans among the top two most important crops they produce in terms of area planted (on average a farmer planted 0.4 ha for bean production). Beans, planted as part of the traditional intercropped system called *milpa,* are most commonly planted simultaneously (or directly) with corn, although the relay (*milpa relevo)* system is also practiced by one out of every five farmers in this region.

Beans play an important role in the diets of the local population in this region and people perceive it to be a nutritious food relative to other commonly consumed food items. Beans are consumed throughout the year, but own production is not sufficient to meet the bean consumption needs for most farmers in this region; they rely on purchased beans to fill this deficit. Thus increasing productivity of bean crop can increase bean security, and potentially enhance nutritional outcomes by increasing the quantity and frequency of bean consumption.

To guide future bean breeding efforts targeted for this region by the SO1.A1 team, farmers were also asked to rank different varietal trait preferences they would like to see in new bean seed. The results for men and women respondents grouped into five varietal traits are presented in Figure 1. These include: 1) Visual traits: size and color; 2) Productivity (yield, disease resistance and resistance to insects); 3) Storage and Culinary traits (cooking time, taste of green beans, taste of dry beans and resistant to storage pests); 4) Agronomic traits (early maturity and anti-lodging); and 5) Marketability (easy to sell). Overall, the top trait indicated by farmers was either visual traits or productivity traits (60%) as seed in Figure 1.

Top preferences for size and color, storage and culinary quality traits, and marketability did not differ between men and women respondents. However, women farmers preferred as the top characteristic productivity traits on average more than men farmers at $p<0.05$; while men preferred agronomic traits (early maturity and anti-lodging properties) as the top characteristic more than women at $p<0.05$ (See Figure 1). If a variety with the preferred traits was made available, farmers were willing to pay on average 6.06 Quetzales/lb of bean seed of that improved variety. Women farmers were willing to pay about 0.16 Quetzales per lb. more than men counterparts for seeds of improved variety with preferred traits. However, this difference is not statistically significant (Table 1).

We estimated the determinants of farmers' willingness to pay for bean seed of preferred variety using regression analysis, and found that farmers' willingness to pay (WTP) for improved quality bean seed of preferred variety was highly correlated with farmers' poverty score, area planted to bean production, and gender. For example, all else equal an increase of 1 point in the poverty score (i.e., decreased probability of being poor) was associated with a 0.6% increase in WTP. All else equal, an additional *manzana* (0.7 ha) of bean production area (i.e., farmers growing more beans) increased WTP by 5.1%. All else equal women farmers were willing to pay 7.3% more than men farmers for bean varieties of their preferred traits.

The regression results confirm that men and women farmers have slightly different preferences for varietal traits. On characteristics traditionally considered to be more important for women than men (i.e., cooking quality, size and color), there was no significant difference in their ranking by men and women. The analysis did not find specific characteristics of bean varieties for which farmers were willing to pay a price premium. The average WTP for bean seed was 6.06 Quetzales/lbs (about $0.80), which reflects about 10% premium over the grain price. This indicates that even for improved bean varieties with preferred traits, most farmers in this region cannot afford to pay a premium price for bean seed that can cover the cost of making quality seed available to them.

The results of this study on varietal preferences have important implications for bean breeding research and seed dissemination efforts. Overall, size and color of the bean, and productivity traits (i.e., yield potential and resistance to stresses) were the first and second most important traits preferred by both men and women. **The study confirms that men and women farmers have slightly different preferences for varietal traits, but the ranking of different types of traits was the same.** On characteristics traditionally considered to be more important for women than men (i.e., cooking quality, size and color), there was no significant difference in their ranking by men and women.

The study did not find specific characteristics of bean varieties for which farmers were willing to pay a price premium. The average WTP for bean seed was 6 Quetzales/lbs (about $0.80), which reflects about 10% premium over grain price. This indicates that **even for improved bean varieties with preferred traits, most farmers in this region cannot afford to pay premium price for bean seed that can cover the cost of making certified seed available to them.** Thus, any efforts to make quality bean seed of improved varieties accessible to these communities will have to rely on subsidy based approaches or innovative profit-based models that can lower the cost of locally producing quality seed (albeit not certified per legal definition) and making them available to farmers in this remote areas of Guatemala at affordable prices.

Progress report on publication outputs: A report summarizing the descriptive results of the farmer survey is forthcoming as AFRE Department Staff Paper 2017- 08. Cleaning and organizing of survey dataset is ongoing, and will be registered and made available on USAID’s DDL website by the end of November 2017.

1b. Analysis of existing data for strategic insights to guide impactful research on legume based farming systems

Legumes impart several agronomic, environmental, and economic benefits to smallholder farm households. As natural nitrogen fixers, legumes reduce the need for inorganic fertilizer and enhance long-term soil fertility and productivity. Due to their high protein, mineral, and fiber content, legumes also carry nutritional benefits. Legumes therefore likely play a positive role in ensuring a household's food security through two pathways:

- The income pathway (i.e. increasing the productivity and income-generating capacity of the production system), and
- The consumption pathway (i.e. increasing the diversity of nutrient-rich food for self-consumption).

Following up on the work conducted in Zambia in the previous year, in FY 17, the project team undertook a similar research activity in Uganda using existing data to build an evidence base by exploring pathways through which legumes potentially enhance agriculture-food security linkages. Specifically, we examine the links between the various ways in which households incorporate legumes into their cropping activities (namely, rotations with cereal or other crops, inter-cropping with cereal or other crops, or mono-cropping) and several indicators of household food security and welfare along the agricultural production and income pathways (Figure 2). The legumes commonly grown in Uganda and included in the study are Beans, Field peas, Pigeon peas, Chick peas, Groundnuts, Soybeans. We give a brief overview of the methodology, emerging results, and need for further research.

Method: Three rounds of the Living Standard Measurement Survey (LSMS) data for Uganda, representing years 2009, 2011 and 2013 were used for this analysis. A subsample of households who grew legume crops at least in one plot in any of these three years was included in the analysis. The analytical sample consists of 3,390 Households comprised of 1,130 HHs from each wave. Data were analyzed at the household level using panel data methods (i.e., pooled OLS and household fixed effects). The aim of these analyses is to assess the impact of the adoption of legume intercropping, legume rotation and legume mono-cropping practices on crop income, calorie and protein production, and indicators of household food security and diet diversity.

Main Results: Figure 3 shows the extent to which legume-based cropping practices are adopted by farmers in Uganda. Note that these are not all mutually exclusive practices. A household may be using multiple practices on different plots in a given year. On average the adoption rate of different technologies in each of the waves is around 50 %. For some reason, the percentage of households practicing these different technologies was smaller in 2013 compared with 2011 and 2009 (fig 3). Mean comparisons (using t-test) of outcome indicators between users and non-users of these practices indicated positive correlation between the legume based cropping practices (i.e., intercropping and rotation) and the outcomes, which is encouraging.

Preliminary regression results using the pooled OLS and household fixed effects methodology showed **significant effects** of legume based technologies on food production (i.e., calories) and nutrient production (i.e., protein). However, the effects of individual technologies on other indicators down the impact pathway are mixed (Table 2).

The positive correlation between legume based cropping practices and some of the production, income, consumption and dietary diversity outcomes pointed out by this study is encouraging. However, rigorous analysis that control for selection bias and the issue of endogeneity is needed to assess any causal link between these different agricultural practices and nutritional outcomes, and to assess which pathways are contributing to those impacts (if impacts can be attributed to legume technology).

In summary, the two case studies conducted over the last two years using nationally representative data from Zambia and Uganda suggest that incorporating legume crops in cropping system either as rotation crop or inter-crop have positive effects on some indicators of household income, production, food security and dietary diversity. **The most robust effects are on the production of calorie and protein per capita.** From a policy perspective, the empirical evidence that legume rotations and inter-cropping can improve food production and food access among smallholder farmers, points to the need to promote these practice where it is feasible for farmers to do so. Researchers from NARS together with social scientists in these countries should investigate the specific types and lengths of cereal-legume rotations that are the most welfare-enhancing for Zambian and Ugandan smallholders. Further research is also needed to understand the low adoption rates of cereal-legume intercropping among Zambian smallholders, and to identify and promote specific cereal-legume intercrops that meet farmers' needs.

Progress report on publication outputs: A paper summarizing the results of the Zambia study has been published as an MSU International Development Working Paper, and revisions are underway for publication as an IAPRI working paper. The Uganda analysis and preliminary results were presented as a poster paper at the Legume Innovation Lab conference in Burkina Faso in August and as an oral presentation at the Mastercard Foundation Scholars event on campus in October. The graduate student funded by Mastercard Foundation plans to extend and further refine the analysis for Uganda as part of her thesis research. Eventually, we plan to submit two manuscripts (one for each country) for consideration in a peer reviewed Ag Econ journal.

Objective 2. Conduct ex ante and ex post impact assessments

2a. Sustainability of legume seed system constraints and opportunities to guide policies and programs

Two studies were initiated/completed in FY 15 (Tanzania) and FY 16 (Ghana) under this broad theme. This line of research was further extended in FY 17 to include the following three country-specific studies.

i. ***Willingness of small holder farmers to pay for quality seed—Study in Nicaragua:***

Benefits from plant breeding research that generates new varieties with improved agronomic and nutritional traits (i.e., biofortification) can only be transferred to farmers if those varieties are officially released, and good quality seeds of such improved varieties are available to and planted by farmers. To date the plant breeding program of the Nicaraguan Research System (INTA) in collaboration with HarvestPlus and CIAT has released two iron biofortified bean varieties. However, the delivery of improved seed to farmers is happening at a small scale. Farmers can potentially use three types of seeds of these improved and biofortified bean varieties—certified seed, quality-declared seed (referred locally as Apta Seed) or recycled grain as planting material. This study was carried out in collaboration with CIAT/HarvestPlus in Nicaragua to address the following three objectives:

1. Analyze the agronomic performance of these three types of planting materials: certified seed, apta seed, and recycled grain.
2. Quantify the premium farmers are willing to pay (WTP) for these alternatives, using two methods—bidding auction experiments (BDM) and real choice experiments (RCE).
3. Test the impact of information treatment about the high iron content (and nutritional benefits) of the variety on farmers' WTP for quality seed.

Method: To address these objectives, double-blind farmer-run demonstrative field experiments were established in the first season of the year (May-August 2017) in 12 villages in Nicaragua, distributed across four departments and six municipalities. However, later in the season two of the villages were excluded from the study because one was planted too late (and could not carry out the field days on time) and another was completely lost by pest damage.

Specifically, to address objectives 1 and 2, a two-step approach was used. First, the double-blind demonstrative fields allowed experts to track the management given by the farmer, and to estimate yields, in addition to allowing farmers to learn first-hand how the different types of seeds of the same improved variety performed in a location that is close to their farm and under farmer management. Second, once farmers learned how the different types of seeds performed, a bidding experimental mechanism and a real choice experiment were carried out to extract information about how much they were willing to pay for these seeds based on their perceived or observed differences in performance. To address objective 3, information about the high iron content of the improved variety, and the benefits of consuming these beans was provided to farmers using a poster as a visual aide. This information treatment was given to farmers in half of the villages prior to implementing the bidding/choice experiments.

In each field, three plots with different qualities of bean seed of an iron-rich biofortified variety named INTA Ferroso were planted: Certified Seed (which was purchased from the government seed vendor in 2017 at a price of $1.15/lb), Apta or quality-declared seed (obtained at a price of $0.60/lb) and recycled grain (purchased at price $0/48/lb). The Apta and recycled grain were both produced by farmer-run community seed banks. It should be noted that since INTA Ferroso is a relatively new variety and not yet widely disseminated to farmers, the recycled seed used in these experiments was simply one generation advanced seed produced by the seed bank (i.e., it represents recycled grain by CSB, not the farmer).

To maintain the blindness of the experiment, the demonstration plots were marked using symbols: a circle for certified seed, a square for apta seed and a triangle for recycled grain. Neither the field technicians, nor the farmers managing the fields knew which symbol corresponded to which seed type; hence the experiments are considered double-blind. Two field days were organized in each village where all farmers in the village were invited to participate. The first field day was done soon after flowering, and farmers evaluated the plots and ranked them, and a census of participants was done. The second field day was done near maturing, and farmers evaluated the fields a second time, ranked them, and both the bidding mechanisms (i.e., the Becker-DeGroot-Marschak method and the real choice experiments) were carried out in each village in that order. Although all farmers who participated in the first field day were invited to the second field day, some did not attend. Further, some farmers participated in the second field day, but not the first one.

Results: Yields, standardized to 14% moisture, varied across locations (**Error! Reference source not found.**3). Analysis of agronomic data suggest that the low yields observed in villages El Porcal and Ojo de Agua were due to a poor crop management and the low soil quality. The villages with the highest grain yield (average of the three seed types) were B3 (Las Mesas Sur), A5 (Moropoto) and A1 (Santa Rosa), followed by all other villages. On average, apta seed yielded more, followed by recycled grain and certified seed. This probably was due to, in addition to crop management, the quality of the planting materials, as determined by its germination rates: 91% for apta seed, 86% for recycled grain and 78% for certified seed.

To statistically test the mean yield difference across treatments, an analysis of variance (ANOVA) was carried out (**Error! Reference source not found.**3). As can be seen, on average seed obtained from the community seed bank (i.e., apta seed) yielded statistically significantly more than certified seed obtained from a government vendor. This suggest that high-quality, low-cost seed can be made available to farmers using a community based approach. Furthermore, there were no statistically significant differences in yields between recycled grain (obtained from the same community seed bank as the apta seed) and either apta or certified seed.

Results from the second field day evaluation showed that 78% of farmers selected the square symbol plots planted with apta seed as the best plot (Table 3), far more than percentage of farmers ranking circle and triangle plots as the best plots (11% and 10%, respectively). Although farmers did not know the identity of the seed type, nor the actual yields, their ranking of plots during field day 2 (based only on visual characteristics of plant growth) are consistent with the yield results (Table 3).

Results from both the BDM and RCE exercises show that most farmers were willing to pay a premium for high quality seed, as perceived by them during the second field day evaluation of the plots. Results for the BDM are presented in Table 4. On average, farmers were willing to pay more than double the price of reported grain price for the highest ranked quality seed (which was plot square) and about 65-70% over the reported grain price for the lower ranked quality seed (i.e., plot circle and triangle). Finally, bivariate statistical test suggest that providing information about the high iron content of the variety did not have any statistically significant effect at the 10% level in farmers' WTP for any of the seed types (Table 4). The average price premium farmers are WTP for highest rated seed type (which turned out to be apta seed in this case) over lowest rated seed type (which turned out be recycled grain) is about 33%, which is similar to premium price we had estimated for beans in Tanzania, but lower than estimated for cowpea in Ghana (73%).

ii. ***Willingness of small holder farmers to pay for quality seed—Study in Burkina Faso:***

Similar to the study in Nicaragua, Ghana, and Tanzania, the goal of this research conducted in Burkina Faso this year was to understand cowpea farmers' willingness to pay (WTP) for certified, quality declared and own-saved or recycled cowpea seeds. Specific research questions addressed include:

a. Do farmers perceive any difference in quality (performance) between the 3 types of seed or planting materials?
b. How does the perceived differential performance of different types of seeds translate into farmers' WTP for these seeds?
c. What factors determine the WTP for each type of "seed" product?

Method: The Becker-DeGroot-Marschak experimental method was used to elicit information on how much cowpea farmers are willing to pay for certified, QDS and recycled seeds based on their perceived/observed differences in their performance. The experiment was conducted with individual farmers. Each farmer received an initial endowment of 1500 FCFA to purchase one kilogram of cowpea seed of an improved variety that varied in 'quality.' The study in Burkina Faso was different from other past studies in two ways. First, instead of conducting double blind field experiments and allowing farmers to observe the performance of plants in actual fields, farmer was presented with pictures of two farmer plots planted to each of the three types of seed products, one picture at the flowering stage and the other at the harvest stage. The plots were simply labeled as plot G, L or M. The identity of the seed quality type planted on these plots was not revealed either to the enumerator of the farmer. In this sense, these were double-blind exercises. The farmers were given some time to visually perceive the performance characteristics or key quality attributes of each seed plot based on the high quality color pictures printed on legal size papers, after which he/she was asked to reveal the willingness to pay for each seed product (type G, L or M). Secondly, in this study we also included a non-blind experimental component. In the non-blind experiment, each farmer were shown three one kg sample of cowpea seeds of the same variety—certified, QDS, and recycled. Farmer expressed their bid for each of these three seed types knowing which of the three seed types they were bidding for. This was done before the picture based exercise. Once the farmer had expressed his/her bid for the three seed types based on labeled seed samples (non-blind), and the three seed types based on plot pictures labeled as plot G, L and M (blind), one of these bids was randomly selected, and a random price was determined to decide whether the farmer purchased that seed at the random price or kept the endowment money.

The study was conducted in 20 villages cutting across 4 provinces in Burkina Faso (Bazega, Boulgou, Gansourgou and Zoundweogo). From each of these villages, 16 households were selected. This resulted in a total sample size of 320 cowpea farmers.

Main Results: The results of the blind experiment suggest that farmers perceived quality attributes associated with different seed types based on plant performance at the flowering and harvest stages. Approximately 86% of the farmers surveyed rated plots planted with certified seeds (plot G) as the best plot, while 13% rated the plot planted with quality declared seeds (plot L) as the best seed plot. Farmers' perception of the performance of each seed type was also reflected in their bids—average bidding price per kilogram was 1226 CFA for seed type G (i.e., certified seeds), 1058 CFA for seed type L (i.e., QDS), and 653 CFA for seed type M (i.e., recycled or own-saved seeds). These prices were also higher than the average price of cowpea grain sold in the market (396 CFA/kg) as reported by the farmers (Figure 4).

Farmers are willing to pay a premium for quality seeds if quality seeds are available. There is a demand for quality cowpea seeds. However, access to these seeds remain an important challenge for cowpea farmers in Burkina Faso. Farmers who did not win the 1 kg of seeds that was randomly offered for sale were very disappointed. As observed by these farmers, quality seeds are difficult to find even when they have money to buy the seeds. These findings suggests the need for investments in cowpea seed value chain to increase the availability of quality seeds—for example, seed multiplication and further production, seed quality assurance system, and seed distribution.

The number of farmers willing to pay a premium price for quality seed declined as the price of seed increased. This finding, which is similar to other studies conducted under this sub-objective, also suggest the need for interventions to reduce the cost of seed production, thereby reducing the price of quality seeds, and consequently making the quality seed affordable to more number of farmers.

Summary of key findings and implications from research on farmer willingness to pay for quality seeds: We would like to summarize the main findings and implications emerging from the four studies conducted so far under this sub-objective in different countries and for two legume crops (beans and cowpea).

Finding # 1: Quality seeds do perform better in terms of important characteristics (i.e., germination rate, yield, etc.) relative to recycled grain of legume crops.

Implications:

- To increase productivity, it is not sufficient to promote only the adoption of improved varieties, but also quality seed
- Need more experimental evidence on productivity differences in seed types

across legume crops and countries to confirm or challenge the notion that self-pollinated crops such as beans and cowpeas do not suffer from yield loss (from seed quality deterioration) due to recycling seeds for up to five or more generations.

Finding # 2: Farmers are able to perceive quality differences in planting material and are willing to pay a premium for QUALITY seed

Implications:

- Further research is needed to assess the quantity of seed farmers would be willing to buy at a premium price and the frequency. This information will help gauge the size of the demand for quality seed.

Finding # 3: Although the bidding experiments reveal that about 30-35% of farmers' WTP for quality seed was above the price of certified seed, in practice farmers' use of purchased certified seeds or QDS is much lower than reflected in the percentage of farmers WTP a premium for quality seed.

Implications:

- Further research is needed to investigate whether the low (actual) demand for quality seed products is a trust issue (i.e., counterfeit or inferior seed) or availability issue (i.e., supply side constraint)?

Finding # 4: Number of farmers willing to pay a premium price for quality seed declines as price of seed increases (i.e., results are consistent with the downward sloping demand curve). Across all the countries studied, we find that there are a significant proportion of legume growing farmers whose willingness to pay a premium for quality seed is much lower than the existing certified seed to grain price ratio.

Implications:

- Need multi-pronged approaches to meet the seed needs of all the farmers across this spectrum of WTP. Current efforts to promote private sector to produce and supply certified seeds can potentially meet the seed needs of at most 30-35% of farmers (if the quality of those seeds is substantially superior to recycled grain).
- More research and discussion needs to happen to address the seed needs of a majority of farmers (two-thirds or more) whose WTP for quality seed is below the price at which certified seeds are sold in the market. Research is needed on how to lower the cost of quality seed production so that per unit cost can be brought closer to grain price, without lowering the profit margins for seed producers to stay in business. For example, training and capacity building of seed producers, supporting the development of new innovative technologies for seed production, and quality assurance monitoring system, that can both lower the cost of quality assurance system and reduce the rejection of seeds that don't meet quality standards, can increase the 'seed' yield, and thus lower the cost per unit of 'seed' produced.

iii. Case study on community based seed system in Nicaragua

One of the innovative approaches to produce and disseminate low cost quality bean seed to farmers in Nicaragua that was used by the BTD project was the Community Seed Banks (CSB), a model promoted by the Government of Nicaragua as a mechanism to promote quality seed availability at the community level. Between 2011 and 2013, the BTD project supported or helped create a network of 234 CSBs across the country and an estimated 16,065 farmers obtained seed from these project supported CSBs, which represented 23% of farmers cultivating beans on 10 MZ (7 hectares) or less. The seed produced by the CSBs was from Registered Seed but called *Apta* seed because it was not certified. It was not Quality Declared Seed because no such category of seed exists in the Nicaraguan seed law. The CSB leadership determined various pricing mechanisms (mostly in-kind exchange of seed with grain), often depending on their relationships with the clients.

A study of the cohort of CSBs established in the first year of the BTD project found that many seed banks had failed (or ceased operation) after 1, 2, or 3 years, and only some were still functioning in 2014 when the BTD project had ended. The analysis of the data collected in 2012 using survival analysis technique, reinforced the importance of seed marketing training, production of quality seed, inclusive transparent operations, and experienced leadership as factors contributing to the longevity, and thus sustainability, of CSBs. While these results were important, the study was limited to a time period in which the CSBs received external financial and technical support.

To further understand the factors contributing to sustainability of CSBs, and specifically, after external financial support in the form of the BTD project ended, a follow up study in collaboration with CIAT was conducted this year. The study was designed to sought to explain why some CSBs discontinued operations and if the model is scalable both in Nicaragua and in other countries. The methodology and main results emerging from this study are reported here.

Method: While the baseline study was limited to CSBs that began operation in 2011, this follow up study included a sub-sample of CSBs surveyed in 2012, and new CSBs initiated between 2011 and 2014. A total of 81 CSBs were surveyed from 13 departments and 47 municipalities by trained enumerators. The survey took place between 7-22 June 2017.

Main Results: By combining the baseline data with data collected in the follow up study, we are able to increase the number of observations from 154 to 180 CSBs. The data from the follow up study also increased the years of survival (the dependent variable in our duration analysis) from three years in the baseline study to six years. Table 5 provides descriptive statistics of the variables included in the duration analysis.

The results of the duration analysis technique identify several CSB characteristics as associated with longer operation as well as lower risk of failure. As would be expected, yield was positively associated with survival (an increase in yield by 100 lbs per mz increased survival by 3%). Likewise, cost recovery measured by client repayment for purchase of seeds was positively associated with survival (survival increased by 3.5% as cost recovery increased by 10%). Access to productive assets, such as a silo, increased survival for CSBs. Holding all else constant, CSBs with seed marketing training survived 87% longer than CSBs without such training, and helped the survival of CSBs with low yield potential.

CSBs with high levels of clients (beneficiaries) per manzana of seed production (i.e., higher intensity of operation) had higher risk of failure. Seed quality data reveal that CSBs are widely distributed across quality standards as measured by acceptable humidity level (maximum of 15%), seed germination rate (minimum 80%), and purity (minimum 97.5%). Only 23% of CSBs met all three quality standards. An acceptable humidity level was the most difficult standard to achieve (See graphs in Figure 5).

Missing from the 2012 study were the reasons for CSB failure. Of the 81 CSBs in the follow up study, two thirds had ceased operations and an additional 9% of CSBs' operations had been interrupted for at least one year since their inception. Table 6 presents the reasons given for discontinuing or interrupting seed production. Each CSB could give up to three reasons. Surprisingly, the most common reason given for ending the CSB was the impacts of weather that damaged crops[3]. While bean seed and grain production was impacted by weather during the years of study in Nicaragua, these conditions also create an opportunity for NARS to promote drought resistant varieties developed through research. For seed producers this also creates a potential market for their product (i.e., seed) as most farmers would have also suffered weather related loss in grain production and would be looking towards the market for seed to plant in following season.

Several of the reasons for ending the CSBs could be linked together under financial constraints. Namely, the end of INTA financial support at the end of the BTD project (33% of CSBs cited this reason), high seed production costs (reported by 23% of CSBs) and low cost recovery (reported by 11% for CSBs). No availability of registered seeds of preferred varieties from INTA was reported by 26% of CSBs as a reason for ending CSB operations. This is a supply side constraint that needs further investigation to understand why INTA was not able to meet the demand for registered seeds of preferred varieties.

Community based seed production models such as the CSBs have often been criticized as not being sustainable because there is no 'profit' motive to serve as a driver of sustainability. In the case of CSBs, despite their name suggests, banks do operate on the principle of profit-sharing among the membership. This profit that a

[3] Specifically, CSBs listed "poor rainy season, "drought," "two consecutive years of drought," "climate change (drought)," "unfavorable climatic conductions" among others

CSB realizes from its operation can come from two sources of revenues (less cost of seed producing). One is the repayment of grain they receive from farmers. To encourage a culture of valuing quality bean seed, the BTD project suggested farmers pay back 2 pounds of grain for every pound of *Apta* bean seed received. In reality, however, grain repayment was well below the anticipated level. On average, CSBs received 6.61 qq of grain in the form of repayment for every 6.5 qq of *Apta* bean seed distributed to farmers. The value of this average quantity of grain repayment received by CSB is estimated to be about $ 407 per CSB.

A second source of potential economic incentive for CSB membership to get involved in joint seed production is the value of apta seed produced but not distributed to community farmers (i.e., surplus seed production that is potentially available to CSB members to either sell or keep for themselves). Using the survey data and some back-of-the-envelope calculations, we estimate that on average, CSBs produced 1376 lbs of *Apta* bean seed in its first year of production but only distributed 650 lbs to farmers. The remaining 726 lbs represent surplus seed valued at $560 per CSB. It is unknown what portion of this surplus was divided among CSB members, saved for future or used for other purposes. However, this surplus seed plus the value of grain repayments represent potential economic incentives for CSB members, and can contribute to its sustainability. More analysis to examine the underlying economic (or other) incentives that motivate the survival of CSBs is planned for future.

In conclusion, the results of this study reinforce the importance of training, ability to produce quality seed, and access to productive assets in reducing the risk of failure. These features should be taken into consideration when promoting community based seed production / distribution model to increase the probability of its long-term operation and sustainability. This study has also shown that producing bean seed that meets all the quality standards remains one of the challenges of the community based seed system. There is a need to find cost-effective ways for community based seed models to produce seeds that meet the minimum quality standards.

Surprisingly, the most common reason given for ending the CSB was the impacts of weather (mostly drought). While bean seed and grain production was impacted by weather during the years of study in Nicaragua, these conditions also create opportunities for bean seed producers and INTA to promote drought resistant varieties during a period of anticipated high bean seed demand. Future support of models based on local bean seed production should take into consideration the demoralizing impacts of crop failure on new seed producers. A conditional support mechanism, like crop insurance, that supplies periodic infusions of registered seed or financial support triggered by weather conditions or other indicators might increase sustainability of such group based efforts, while avoiding dependence on external funding. In drought prone areas, irrigation might be necessity for seed production and should be included in a viability study before supporting new community based seed production enterprises.

While it would be ideal for CSBs to be able to operate with internal funds, after a few years of external support, it is also anticipated that new business ventures will not be profitable in the first two to four years of operations. The 20 CSBs that listed an end of INTA support as one of the main reasons for failure represent 25% of CSBs interviewed in the follow up study and can be considered as a benchmark for anticipated rate of failure without external financial support.

Integrating community based bean seed production enterprises with the national agricultural research systems such as INTA present an opportunity to increase seed security in local communities. CSBs are one such model that has presented positive short term results as measured in number of small holder farmers receiving improved varieties of bean seed. The results of this study highlight some of the challenges that CSBs face and encourage future iterations of models similar to the CSB model in Nicaragua to consider these lessons learned.

2b. Adoption study in Haiti

In collaboration with the SO1.A4 team, this proposed study was initiated in FY 16 and data collection was completed in FY 17. The study is designed to generate systematic and rigorous evidence on the use of improved bean varieties by farmers in Haiti. Specific objectives of this study are:

a. To conduct a survey of bean farmers in Haiti and collect information on farm characteristics, bean area, varieties planted, sources of seed, criteria farmers use in making seed use decisions (type, quantity, source, etc.), varietal trait preferences, and perceptions on seed quality, price, availability, and constraints.
b. To conduct an assessment of the bean seed supply chain to understand the seed system characteristics, supply and demand side constraints, institutional players involved in different nodes of the supply chain (i.e., producers/multipliers of different generation of seeds, distributors, traders, sellers, and buyers), and strategies/approaches used by the seed suppliers and users to meet the country's need for quantity and quality seed
c. To collect bean seed samples throughout the seed supply chain (i.e., seed producers, distributors, traders, seed and grain vendors, agro-dealers, and farmers) and conduct DNA fingerprinting analysis to identify the genetic identity of bean varieties planted by farmers and available in the 'seed system.'
d. To estimate the extent to which bean seeds of improved varieties are used by farmers and are in circulation in the seed system, and identify major constraints and opportunities for increasing the adoption of quality of bean seeds by farmers in Haiti.

Method: For the household surveys, two sampling frames were used to select two different groups of farmers. The first was a sample targeting 700 farmers drawn from a nationally representative list of bean growers from the 2014 agricultural production survey provided by the Agricultural Statistics and Informatics Unit (USAI) of the Haitian Ministry of Agriculture. The second sample targeted 300 farmers drawn from beneficiaries of the BTD project. Enumerators interviewed farmers from both groups using the same standardized questionnaire.

Data collection occurred in late November and early December 2016, in all departments except Sud and Grand'Anse departments. Due to the effects of Hurricane Matthew, data collection in these two departments occurred in April 2017. Table 1 summaries the number of farmers interviewed (both as representative farmers from the USAI Ag. Production Survey and beneficiary farmers of the BTD project) and the number of seed samples collected for DNA fingerprinting.

Towards objective 2, key informant interviews using a structured questionnaire were conducted with agro-dealers, international and national NGOs, IICA, FAO, and donor funded programs across the country in June-July 2017. A consultant was hired to assist with this task. A sample of 50 seed distributors and 50 seed producers were selected based on a comprehensive list compiled by this consultant. During the interviews, a total of 54 seed samples from these producers and distributors were also collected for DNA fingerprinting.

Also towards objective 2, we piggybacked on the existing infrastructure managed by NASS (i.e., Systeme D'information Sur Les Marches Argricoles (SIMA) and collected bean seed samples and information from 9 bean vendors in 25 markets across the country at three time periods over a period of 12 months--Nov-Dec 2016; Mar-Apr 2017; and Aug-Sept 2017. Since a large number of farmers in Haiti source their bean seeds from vendors in the market, this sample of seeds collected from 25 markets at three time periods capture the temporal and spatial diversity of beans potentially available as planting material for farmers. A total of 2660 bean seed samples were collected from bean vendors in SIMA markets.

Protocols for collecting seed samples, labeling, handling, shipping and storage of seeds from the point of collection to NSS facilities in Haiti, and then shipping these seeds to Puerto Rico were developed with SO1.A4 team. Seed germination and DNA extraction, and GBS library construction was done in Puerto Rico at USDA's facilities. DNA fingerprinting is being conducted at Cornell University. Given the fact that the last seed sample were collected in September and the significant delays caused by hurricane Irma, this component of this study remains incomplete at this point. To date, DNA analysis of farmer samples collected in survey round 1 (from 8 Depts) has been completed, and analysis of market samples collected in round 1 is ongoing. DNA analysis of farmer samples from round 2 (2 Depts); market samples from Round 2 and 3; samples from seed producers and distributors, and reference library accessions is still pending. The plan is to continue these tasks beyond November 30 using other resources.

Main Results: The results of the farmer survey confirmed that farmers were not able to identify varieties by name. Bean seed/variety types planted by farmers were referred mostly by market class (e.g., black bean, red beans, etc.). Farmers reported growing 9 market classes; black bean was the most common bean type planted in Haiti (Table 8). When asked for the names of the varieties planted, 63 percent of farmers gave black bean (Pwa Nwa or Pois Noir) as the variety name, 10% reported cream (Pwa Be) as the variety name, 8% listed white (Pwa Blan) as the name and 7% reported red (Pwa Wouj). Improved varieties Aifi Wuriti (given as Arifi), DPC40 and Icta Ligero were only mentioned once each. Variety Arroyo Loro Negro (given as Awoyo) was mentioned 4 times. Farmer inability to recognize variety names further emphasizes the importance of DNA fingerprinting of seed samples collected from farmers to identify the use of improved varieties. Relying only on the varietal names given by farmers would give unreliable estimates of varietal adoption.

The Seed System Security Assessment conducted in Haiti post-earthquake (Sperling et al. 2010) determined that about 80% of bean seed was acquired from local grain markets. The importance of the local grain market as the source of seed is confirmed in our study as the majority (84%) of farmer reported purchasing seed from a grain vendor when they first acquired the bean seed they were currently using. Farmer reported only 5% of first seed source of varieties they were currently planting came from institutions and organizations (NGOs, seed aid, government and FAO), 3% from the private sector (input dealer and seed grower), and 3% from local sources (e.g., Madam Sara, Farmer groups, cooperatives and other farmers or family).

In the most recent season, farmers still purchased the majority (72%) of the bean seeds from grain vendors. Farmers across both sample frames (i.e., USAI production survey and BTD beneficiaries) reported saved seed from previous harvest (13%) as the second important source of seed. The fact that 13% is the same figure of seed from own stocks found in 2010 by Sperling could point to a long term trend in farmer seed sourcing practices or indicate that the acute challenges of 2015 and 2016 (such as Hurricane Matthew) had resulted in conditions of seed availability similar to those in 2010 following the earthquake.

Farmers were also asked about any free or subsidized seed they had received in the past five years. Surprisingly, only 148 BTD farmers (51%) provided information about receiving free or subsidized seed. Among the varieties reported by BTD farmers, only 3% were the names of improved varieties while 92% reported the variety as “black bean.” The study found no evidence that farmers successfully save seed stocks of their own production for future planting after receiving free or subsidized seed. The main reason given by BTD farmers for no longer using a variety they would have obtained from seed distribution programs is that they sell most of their beans harvested and there is no seed available (87%) after that program ends. The varieties that farmers continue to use depend on the seed availability from outside sources. Only 14% of the varieties received by BTD farmers and 38% of the varieties received by non-BTD farmers that are still used are saved from the farmers saved seed stocks of their own production.

In summary, the results of the farmer survey in Haiti point to the challenge of sustaining the use of improved varieties once they are disseminated to farmers through a systematic seed dissemination efforts such as the BTD project. This is due to the fact that most farmers sell their harvest and don’t save seeds for the next planting. Secondly, the bean varieties have no name recognition, which makes it difficult to track improved varieties disseminated through formal channels. In this circumstances, DNA fingerprinting offers the best approach for varietal identification and estimating varietal adoption. DNA analysis of the first round of farmer samples indicate that approximately 1/3 of these samples were older generation improved varieties such as Arroyo Loro Negro which has BCMV resistant gene. The SR2 marker present in new generation of bean varieties was found in samples in proximity to Mirebalais, Jacmel and SE Haiti (Savane Zombi)--areas where the Legume Innovation Lab and previous Bean/Cowpea CRSP projects have worked and release germplasm. But in a broader picture, the levels of current use of these varieties may be low. These are still tentative conclusions, as 20% of farmer samples and 100% of seed samples collected from seed value chain, include the bean markets still remain to be analyzed.

2c. Follow-up survey in Burkina Faso for impact assessment of biocontrol IPM research

Cowpea (*Vigna unguiculata*) is an important staple in Burkina Faso as well as many other countries in West Africa. Among the major cowpea pests affecting the crop are the legume pod borer (*Maruca vitrata*), flower thrips (*Megalurothrips sjostedti*), bruchids (*Callosobruchus maculatus*), and pod-sucking bugs, for which conventional plant breeding has not been effective and the use of pesticides has economic, health and environmental limitations. Through support from the predecessor CRSP and the current Legume Innovation Lab, the SO1.B1 project team has developed alternative strategies to control these insect pests and reduce the levels of pesticide used on the crop. One of these strategies includes implementing a comprehensive bio-control program. As part of this strategy, the SO1.B1 team had planned to release bio-control agents in selected locations in Burkina Faso where baseline data were collected by this project in 2012. The baseline sample covered a total of 560 households distributed across 56 villages and 10 provinces. In FY 17, the plan was to conduct a follow-up survey (in collaboration with INERA) of the same farmers in 56 communities to be able to evaluate the impacts of bio-control research using difference-in-difference methodology. However, due to several factors beyond the control of this project team (i.e., required approvals for releasing biocontrol agents by the SO1.B1 project, building capacity of INERA for mass rearing parasitoids as biocontrol agents, etc.), the first release of these bio-control agents did not occur until mid-2016 in few locations. Given the long time that had elapsed between the baseline survey and the intervention, and the short time since the release of the biocontrol agents and the planned end line survey, the focus of the survey was changed from assessing the impact of biocontrol strategy of pest control to assessing farmers' preferences for chemical versus biological pest control methods. We describe the objectives, methodology and main results of this study.

Objectives: This study was designed to address three objectives: 1) to understand cowpea farmers' preference for pest control strategy (biological versus synthetic pesticides); 2) the factors that influence cowpea farmers' choice of a given pest control strategy, and 3) the effects of sharing information on the health and environmental consequences of synthetic/chemical versus biological pesticides on farmers' preference for a given pest control strategy. The study was designed in collaboration with INERA, Institut de l'Environnement et des Recherches Agricoles (INERA) in Burkina Faso.

Method: The study used a survey-based discrete choice experiment (CE) method to: elicit farmers' stated preferences for (or predict the adoption of) biological pest control strategy compared to existing pest control methods based on synthetic/chemical pesticides; and to understand the effect of sharing the information about the health and environmental impacts of alternative pest control method on farmers' preference for biological versus chemical pesticides. Thirty-three (33) villages from seven provinces were selected from the pool of villages surveyed in 2011. In each village 16 households were surveyed—10 farmers from the baseline sample and an additional six (6) farmers were selected from each village by the enumerators. The total sample size for the study was 528 households. The sample was randomly assigned to one of the three information treatment groups—those that received information on: a) the health effects, b) the environmental effects, and c) both health and environmental effects. All farmers were presented the same 12 scenarios of discrete choice sets (in random order) before (block 1) and after (block 2) the information treatment. An example of one of these choice sets is given in Figure 9. It presents a farmer three options to select from which had different attribute values associated with them. The attributes were presented for a 0.5 ha cowpea plot and included: the method of pest control (synthetic, biological or none), input cost, labor cost, and expected cowpea production.

Main Results: Survey results indicate that about 6% of the market value of harvested cowpea grains is allocated to purchasing chemicals for pest control. For cash-constrained farm households, this expenditure is nontrivial.

The descriptive results indicate that cowpea farmers' preference for synthetic pesticides decreases with the information treatment. Prior to receiving information on the harmful effects on health and environment of synthetic pesticides, 33% of the sample (N=528) revealed a preference for synthetic pesticides. However, after the information treatment, only 10% of the farmers in the sample would still choose synthetic pesticides. The percentage of farmers who would choose organic pesticides increased from 57% before the information treatment to 79% after the information treatment. 10 percent of the farmers chose neither organic nor synthetic pesticides before or after treatment.

Information on environmental and health effects of pest control methods was highly effective in increasing farmers' willingness to pay for organic pesticides relative to synthetic pesticides. Parameter estimates from the mixed logit model suggest a treatment effect of 4.5 times of the effect of environmental information on cowpea farmers' willingness to pay (WTP) for organic methods of pest control— the average WTP for organic method (biopesticides/biocontrol) relative to synthetic pesticides (CFA per 0.5 ha) increased from 12,940 CFA before environmental treatment to 58,320 FCFA after the treatment. Applying health information, the treatment effect was 4.0 – average WTP for organic method (biopesticides/biocontrol) relative to synthetic pesticides increased four times after health information was provided. The effect on average WTP when both treatments (health and environmental information) were administered as estimated at 2.6—bundling the both types of information increased average WTP to 56,480 CFA from an average WTP of 21,540 CFA before treatment.

The findings also suggests that cowpea farmers in Burkina Faso are aware of health hazards from chemical pesticides but continue to use them out of necessity since they lack awareness of safe alternative pest control methods (i.e., biocontrol, viruses), as well as knowledge on how to prepare/access biopesticides.

In general, farmers are willing to pay higher cost and lower production for more safer pest control method relative to synthetic pesticides. There appear to be a high potential for biocontrol strategy to be widely accepted

Overall, these findings suggest the need for the following interventions:

- Systematic campaigns to increase awareness and to provide technical knowhow on the preparation, use and availability of biopesticides, are needed to improve adoption of these alternative methods
- Incorporating the information on the environmental and health effects of alternate pest control methods in these campaigns can significantly improve

Objective 3: *Build institutional capacity and develop human resources in the area of impact assessment research*

This project addressed the objective of institutional capacity building and human resource development through the following activities implemented in FY 17:

a. Research studies conducted in Burkina Faso, Haiti, Ghana and Nicaragua under objective 2 (described above) involved host country PIs/collaborators/students in the planning and execution of field data collection. Host country collaborators from Legume Innovation Lab projects participated in the rapid appraisal visits, development of research design, and training enumerators and field staff in data collection, data entry and analysis.
b. Activities planned under this project involved graduate students in the planning and conduct of field research and write-up of research results. These students were recruited from within the Department of Agricultural, Food and Resource Economics at MSU (see the details on trainees in the Training section). Two of these students are Scholars funded by Master Card Foundation with the aim of empowering youth and building the capacity of the next generation of African leaders.

IV. Major Achievements

We would like to highlight the following emerging 'messages' based on the research results presented in this report.

- The results of the Guatemalan survey of farmers growing beans in the milpa system have important implications for bean breeding research and seed dissemination efforts. Overall, size and color of the bean, and productivity traits (i.e., yield potential and resistance to stresses) were the first and second most important traits preferred by both men and women. The study confirms that men and women farmers have slightly different preferences for varietal traits, but the ranking of different types of traits was the same. On characteristics traditionally considered to be more important for women than men (i.e., cooking quality, size and color), there was no significant difference in their ranking by men and women. The average WTP for bean seed of preferred variety was only 10% higher than the grain price. Thus, any efforts to make quality bean seed of improved varieties accessible to these communities will have to rely on subsidy based approaches or innovative profit-based models that can lower the cost of locally producing quality seed (albeit not certified per legal definition) and making them available to farmers in this remote areas of Guatemala at affordable prices.

- The two case studies conducted over the last two years using nationally representative data from Zambia and Uganda suggest that incorporating legume crops in cropping system either as rotation crop or inter-crop have positive effects on some indicators of household income, production, food security and dietary diversity. The most robust effects are on the production of calorie and protein per capita. From a policy perspective, this empirical evidence points to the need to promote these practices where it is feasible for farmers to do so.
- Quality seeds do perform better in terms of important characteristics (i.e., germination rate, yield, etc.) relative to recycled grain of legume crops. Thus, to increase productivity, it is not sufficient to promote only the adoption of improved varieties, but also quality seed.
- Farmers are able to perceive quality differences in planting material and are willing to pay a premium for QUALITY seed.
- Although, about 30-35% of farmers' WTP for quality seed was above the price of certified seed, in practice farmers' use of purchased certified seeds or QDS is much lower than reflected in the percentage of farmers WTP a premium for quality seed. Further research is needed to investigate whether the low (actual) demand for quality seed products is a trust issue (i.e., counterfeit or inferior seed) or availability issue (i.e., supply side constraint)?
- Across all the countries studied, we find that there are a significant proportion of legume growing farmers whose willingness to pay a premium for quality seed is much lower than the existing certified seed to grain price ratio. Thus, need multi-pronged approaches to meet the seed needs of all the farmers across this spectrum of WTP. Current efforts to promote private sector to produce and supply certified seeds can potentially meet the seed needs of at most 30-35% of farmers (if the quality of those seeds is substantially superior to recycled grain). More research and discussion needs to happen to address the seed needs of a majority of farmers (two-thirds or more) whose WTP for quality seed is below the price at which certified seeds are sold in the market.
- Research indicates that cowpea farmers in Burkina Faso are aware of health hazards from chemical pesticides but continue to use them out of necessity since they lack awareness of safe alternative pest control methods (i.e., biocontrol, viruses), as well as knowledge on how to prepare/access biopesticides. In general, farmers are willing to pay higher cost and lower production for safer pest control method relative to synthetic pesticides. There appear to be a high potential for biocontrol strategy to be widely accepted

V. Research Capacity Strengthening

Unlike other Legume Innovation Lab projects, this project does not have a country-specific collaborating HC institution. We serve as the cross-cutting project that works towards building the institutional capacity and human resources in the area of impact assessment across all the projects of the Legume Innovation Lab.

VI. Human Resource and Institution Capacity Strengthening

16. Short-Term Training

x. Purpose of Training: To collect bean seed samples and vendor information from selected markets across Haiti
xi. Type of Training: Classroom and field testing
xii. Country Benefiting: Haiti
xiii. Estimated USAID funding for activity:
  a. US$ for Instruction: $4,000
  b. US$ for Participants: $500
  c. US$ for Travel: $500
xiv. Location and dates of training: 3 locations in Haiti between November 9-12, 2016
xv. Number receiving training (by gender): 1 Female; 18 Male
xvi. Home institution(s): Ministry of Agriculture, Haiti
xvii. Institution providing training or mechanism: Michigan State University

17. Degree Training in the US or elsewhere

Degree Training (1)

lxxxiv. Name of trainee (First and Last Name): Edward Opoku
lxxxv. Country of Citizenship: Ghana
lxxxvi. Gender: Male
lxxxvii. Host Country Institution Benefitting from Training: None
lxxxviii. Institution providing training: Michigan State University
lxxxix. Supervising LIL PI: Mywish Maredia
xc. Degree Program: M.S.
xci. Field or Discipline: Agricultural, Food, and Resource Economics
xcii. Research Project Title: Farmer willingness to pay for quality cowpea seeds
  a. US$ for Instruction: 0
  b. US$ for Participants: 0
  c. US$ for Travel: 0
xciii. Estimated funding from other sources for activity if not conducted in US (see footnote 1)
  m. Provider of Funds: Master Card Foundation
  n. US$ for Instruction: ~$11,729
  o. US$ for Participants ~$25,104
  p. US$ for Travel: ~$5000
xciv. Start Date: August 2015
xcv. Projected/Actual Completion Date: August 2017

xcvi. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xcvii. Training status (Active, Completed, Pending, Discontinued, or Delayed): Completed

Degree Training (2)

i. Name of trainee (First and Last Name): Sean Posey
ii. Country of Citizenship: USA
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: None
v. Institution providing training: Michigan State University
vi. Supervising LIL PI: Mywish Maredia
vii. Degree Program: M.S.
viii. Field or Discipline: Agricultural, Food, and Resource Economics
ix. Research Project Title: Farmer willingness to pay for quality bean seeds in Nicaragua
   d. US$ for Instruction: $11,729
   e. US$ for Participants: $ 25,104
   f. US$ for Travel: $10,000
x. Estimated funding from other sources for activity if not conducted in US
   q. Provider of Funds: AFRE Department (50% value of Fall semester of Research Assistantship support)
   r. US$ for Instruction: ~$5,800
   s. US$ for Participants: ~$4,000
   t. US$ for Travel: 0
xi. Start Date: August 2016
xii. Projected/Actual Completion Date: August 2018
xiii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiv. Training status (Active, Completed, Pending, Discontinued, or Delayed): Active

Degree Training (3)

i. Name of trainee (First and Last Name): Trhas Weldesghi
ii. Country of Citizenship: Eritrea
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: None
v. Institution providing training: Michigan State University
vi. Supervising LIL PI: Mywish Maredia
vii. Degree Program: M.S.
viii. Field or Discipline: Agricultural, Food, and Resource Economics
ix. Research Project Title: Analysis of existing data for strategic insights to guide impactful research on legume based farming systems
   g. US$ for Instruction: 0
   h. US$ for Participants: 0
   i. US$ for Travel: 0
x. Estimated funding from other sources for activity if not conducted in US (see footnote 1)

u. Provider of Funds: Master Card Foundation
v. US$ for Instruction: ~$11,729
w. US$ for Participants ~$25,104
x. US$ for Travel: 0

xi. Start Date: August 2016
xii. Projected/Actual Completion Date: August 2018
xiii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiv. Training status (Active, Completed, Pending, Discontinued, or Delayed): Active

VII. Achievement of Gender Equity Goals

This project is designed to assess how the technologies and knowledge generated by the Legume Innovation Lab (and its predecessor CRSP) benefits both men and women farmers, entrepreneurs and consumers. Thus, where applicable, 'gender equity' is used as one of the metrics in evaluating the impact of Legume Innovation Lab research. Survey instruments are designed to collect gender disaggregated data on beneficiaries. Where applicable, results of analysis based on primary data are reported by gender to assess the impact on women farmers and other potential beneficiaries of Legume research (see for example the gender disaggregated analysis of varietal preferences and willingness to pay for quality seed in Guatemala).

VIII. Implementation of Data Management Plan

#	Datasets	Year data collection completed	Status
1	Bean Technology Dissemination Project Beneficiary Survey in Nicaragua	2012	Registered and submitted to DDL (July 2016)
2	Bean Technology Dissemination Project Beneficiary Survey in Honduras	2013	Registered and submitted to DDL (July 2016)
3	Bean Technology Dissemination Project Beneficiary Survey in Guatemala	2013	Registered and submitted to DDL (July 2016)
4	Effectiveness and Impact of Mobile Phone based Extension Methods to Disseminate Solar Treatment and Triple Bag Technology for Cowpea in Burkina Faso	2013	Registered and submitted to DDL (May 2017)
5	Survey of Nicaraguan Community Seed Banks	2012	To be registered by end of November; data to be submitted to DDL when requested by USAID
6	Farm household survey data on the Management of Field Insect Pests of Cowpea in Burkina Faso	2013	
7	Household Survey of Guatemalan Climbing Bean Farmers	2015	
8	The Economics of Community Based Seed	2015	

#	Datasets	Year data collection completed	Status
	Production based on the Association Song Koaadba (ASK) model: Farmer surveys in ASK villages		
9	Farmer surveys in two districts in northern Tanzania to assess farmers' willingness to pay for quality bean seeds and farm yield gains	2016	
10	Farmer survey in northern Ghana to assess farmers' willingness to pay for quality cowpea seeds and farm yield gains.	2016	
11	Farm household survey to assess the Management of Field Insect Pests of Cowpea and Choice Experiments in Burkina Faso	2017	
12	Adoption of Improved Bean Seed Varietal Technology in Haiti: Farmer survey data	2017	
13	Adoption of Improved Bean Seed Varietal Technology in Haiti: Market vendor survey	2017	
14	Adoption of Improved Bean Seed Varietal Technology in Haiti: Seed producer and distributor survey	2017	
15	Survey of Nicaraguan Community Seed Banks: Follow up survey	2017	
16	Farmer survey in northern Ghana to assess farmers' willingness to pay for quality cowpea seeds and cost of seed production	2017	
17	Farmer survey in Nicaragua to assess farmers' willingness to pay for quality seeds of a biofortified bean variety	2017	
18	Farmer survey in Burkina Faso to assess farmers' willingness to pay for quality cowpea seeds	2017	

IX. Scholarly Accomplishments

Publications and Manuscripts:

Maredia, M, Shupp, R., Opoku, E., Mishili, F., Reyes, B., Kusolwa, P., Kusi, F., and Kudra, A. 2017. Do farmers economically value seeds of different quality differently? Evidence from willingness to pay studies in Tanzania and Ghana. MSU International Development Working Paper. East Lansing: Michigan State University (*forthcoming*)

DeYoung, David, Byron Reyes, Juan Osorno, Julio Cesar Villatoro and Mywish Maredia. 2017. An Overview of Bean Production Practices, Varietal Preferences, and Consumption Patterns in the *Milpa* System of the Guatemalan Highlands: Results of a

Farm Household Survey. *Staff Paper 2017-08.* Michigan State University Department of Agricultural, Food and Resource Economics Staff Paper Series. (*forthcoming*)

Maredia, M. K., Reyes, B. A., Ba, M., C. Dabire, Pittendrigh, B., & Bello-Bravo, J. Effectiveness of animation videos in inducing technology adoption: A field experiment in Burkina Faso. 2017. *Information Technology for Development (April 19, 2017)* DOI https://doi.org/10.1080/02681102.2017.1312245

Sauer, C., Mason, N. M., Maredia, M. K., & Mofya-Mukuka, R. 2016. Impacts of legume technologies on food security: Evidence from Zambia. *FSP Research Paper No. 36*. East Lansing, MI: Feed the Future Innovation Lab for Food Security Policy. *(December 2016)*

Reyes, Byron A., Mywish K. Maredia, Richard H. Bernsten, and Juan Carlos Rosas. 2016. Opportunities Seized, Opportunities Missed: Differences in the Economic Impact of Bean Research in Five Latin American Countries. MSU International Development Working Paper 151. East Lansing: Michigan State University. *(November 2016)*

Thesis:

Opoku, Edward. 2017. Willingness to pay for quality cowpea seeds: experimental evidence from northern Ghana. Thesis for partial fulfillment of MS degree in Agricultural, Food and Resource Economics, Michigan State University (submitted, October 2017).

Presentations

Oral presentation:

Maredia, M, Shupp, R., Opoku, E., Mishili, F., Reyes, B., Kusolwa, P., Kusi, F., and Kudra, A. Do farmers economically value seeds of different quality differently? Evidence from willingness to pay studies in Tanzania and Ghana. Selected Paper presentation at the 2017 Agricultural & Applied Economics Association Annual Meeting, Chicago, Illinois, August 1, 2017.

Maredia, M K., D DeYoung, E. Prophete, C.D. Joseph, J. Beaver, and T. Porch. "Adoption of Improved Bean Seed Varietal Technology in Haiti: An Assessment Using Farm Surveys, Bean Seed Supply Chain Analysis, and DNA Fingerprinting." Grain Legume Research Conference. Burkina Faso. August 16, 2017.

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Shupp, R., Maredia, M., Reyes, B., Posey, S., Rodríguez, C., and Urbina, R. Towards Improving Access to High Quality Bean Seed in Nicaragua: How Much are Farmers Willing to Pay? Grain Legume Research Conference. Burkina Faso. August 16, 2017.

Me-Nsope, N., Maredia, M,, Shupp, R., and Ilboudo, D. Factors Influencing Cowpea Farmers' Willingness to Pay for Quality Seeds in Burkina Faso. Grain Legume Research Conference. Burkina Faso. August 16, 2017.

Ilboudo, I., Balima, M., and Maredia, M. A local success story on cowpea production and distribution compromised by a national project. Grain Legume Research Conference. Burkina Faso. August 16, 2017.

DeYoung, David and Mywish K. Maredia. "An Assessment of the Local Bean Seed Production and Marketing Model: The Case of Community Seed Banks in Nicaragua." New Models for Legume Seed Business: Resilience, Nutrition and Reaching Farmers at the Last Mile Conference. Washington, DC. March 2, 2017.

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Posters:

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Opoku, E., Maredia, M., Shupp, R., Kusi, F. Willingness to pay for quality cowpea seeds: Experimental evidence from Northern Ghana. Grain Legume Research Conference. Burkina Faso. August 13-18, 2017.

Ray, M., Weldezghi, T., and Maredia, M. Legume Technologies and agriculture-nutrition linkages: Exploratory Evidence from Uganda. Grain Legume Research Conference. Burkina Faso. August 13-18, 2017.

Reyes, B., Maredia, M., Shupp, R., González, C., Rodríguez, C., Urbina, R. Posey, S. Quantifying farmers' willingness to pay for biofortified characteristics in three qualities of planting materials: The case of bean producers in Nicaragua. Grain Legume Research Conference. Burkina Faso. August 13-18, 2017.

X. Achievement of Impact Pathway Action Plan

For this project we have identified two project outputs to be achieved over the life of the project that will contribute towards developing an impact oriented research program that features: 1) Greater awareness among researchers of the importance of achieving developmental outcomes; and 2) Better design of research programs that incorporate strategies and partnerships to transfer research outputs into outcomes and impacts; and 3) Continued and increased support for investments in agricultural research in general, and on legume crops in particular. Towards the impact pathway of achieving this 'vision of success', the following was achieved (cumulatively) as of the end of FY 2017 for each output:

1. Output 1: development of impact pathway analytical tools and guidelines:
    a. Transfer of analytical tools to project PIs and research teams: Completed as planned (in FY 14)
    b. Input and feedback to research teams on their impact pathway: Completed as planned (in FY 14)
    c. Monitor the progress towards projected outputs and strategies to achieving the vision of success as laid down in the impact pathways: Ongoing
2. Output 2: Evidence based assessments of potential and realized impacts of investments in agricultural research:
    a. Publication of results of the assessments in technical reports and peer reviewed venues: Six technical reports, two thesis, one peer reviewed journal article, and two manuscripts for peer reviewed venue have been completed.

ANNEXES

Annex 1. Tables, Figures, and Photos Cited in the Report

Figure 1. Top Varietal Trait Preferences by Gender of Respondents: Results of a Representative Bean Farmer Survey in Western Highlands of Guatemala, 2015

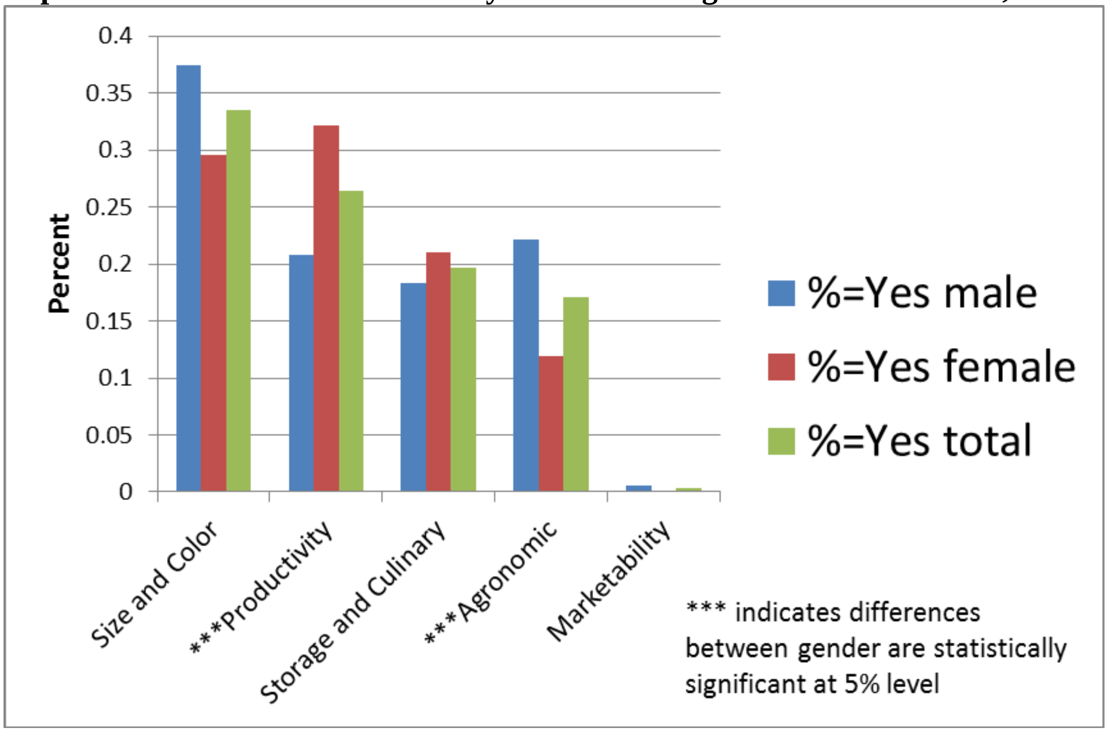
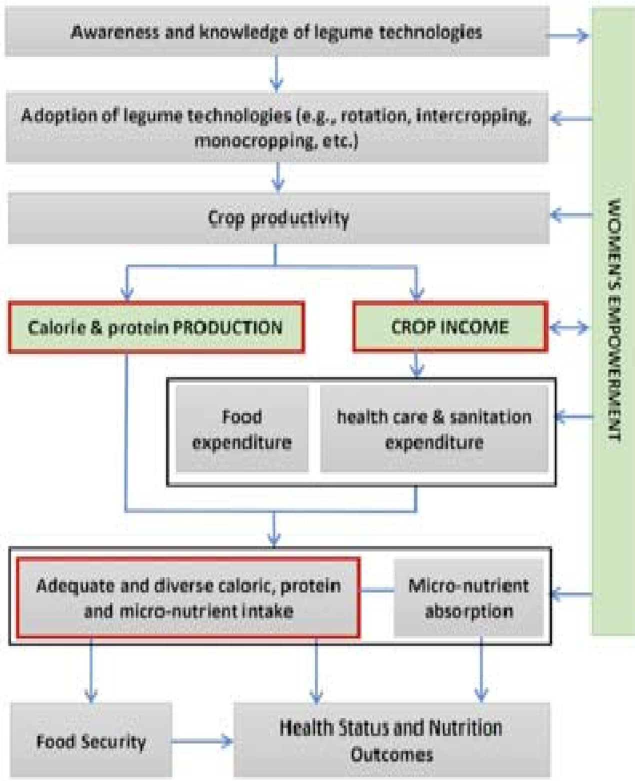
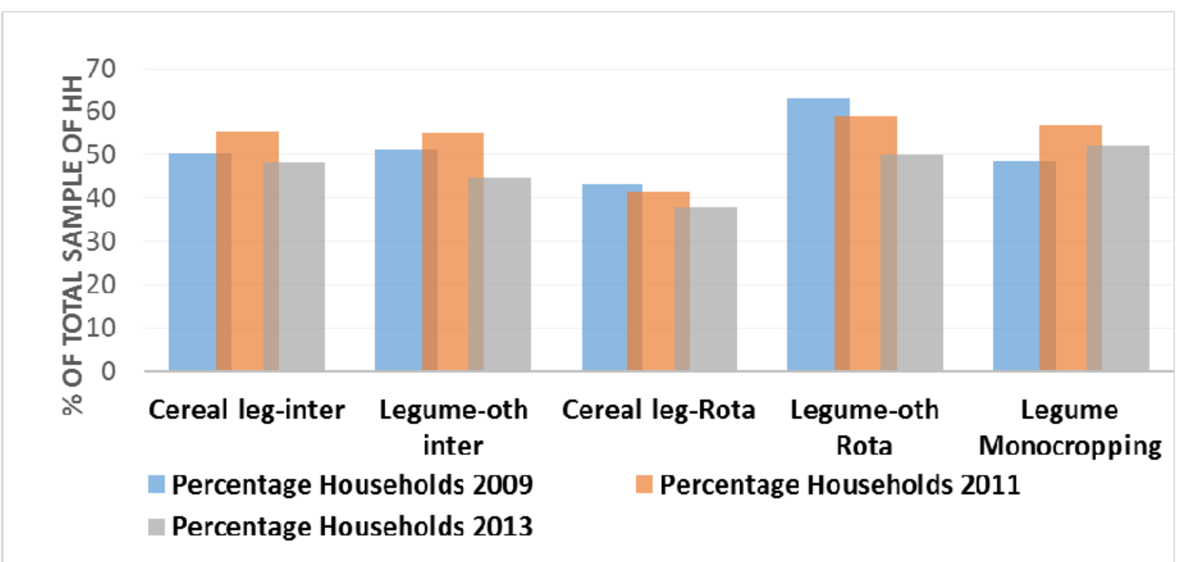


Figure 2: Theory of change: Conceptualized pathways of effects of legumes technology adoption on household food security and nutritional outcomes



Source: Sauer et al. (2016)

Figure 3. Percentage of households practicing different legume-based technologies in the three rounds of LSMS dataset for Uganda



Source: Authors analysis using Uganda LSMS dataset (2009, 2011 and 2013)

Figure 4. Average bidding price (CFA/kg) for different seed types: Results of the blind experiment based on pictures in Burkina Faso (N=320)

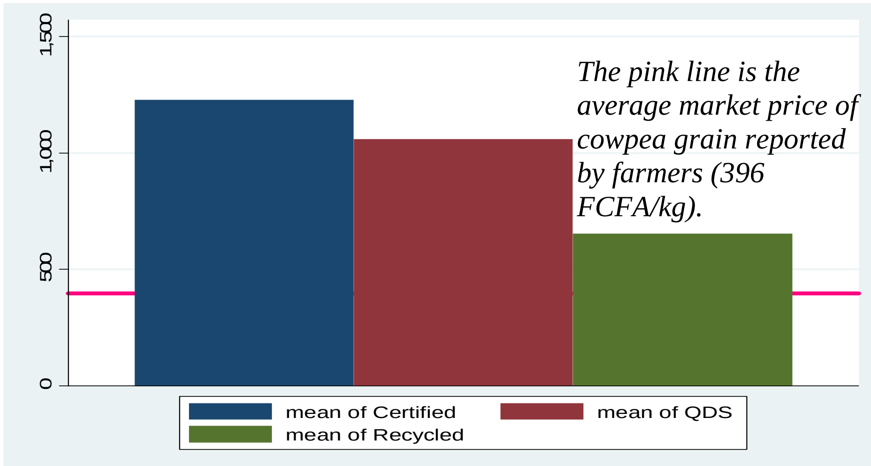


Figure 5: Graphs of Quality Standards Met by CSBs (red line represents minimum standard of quality

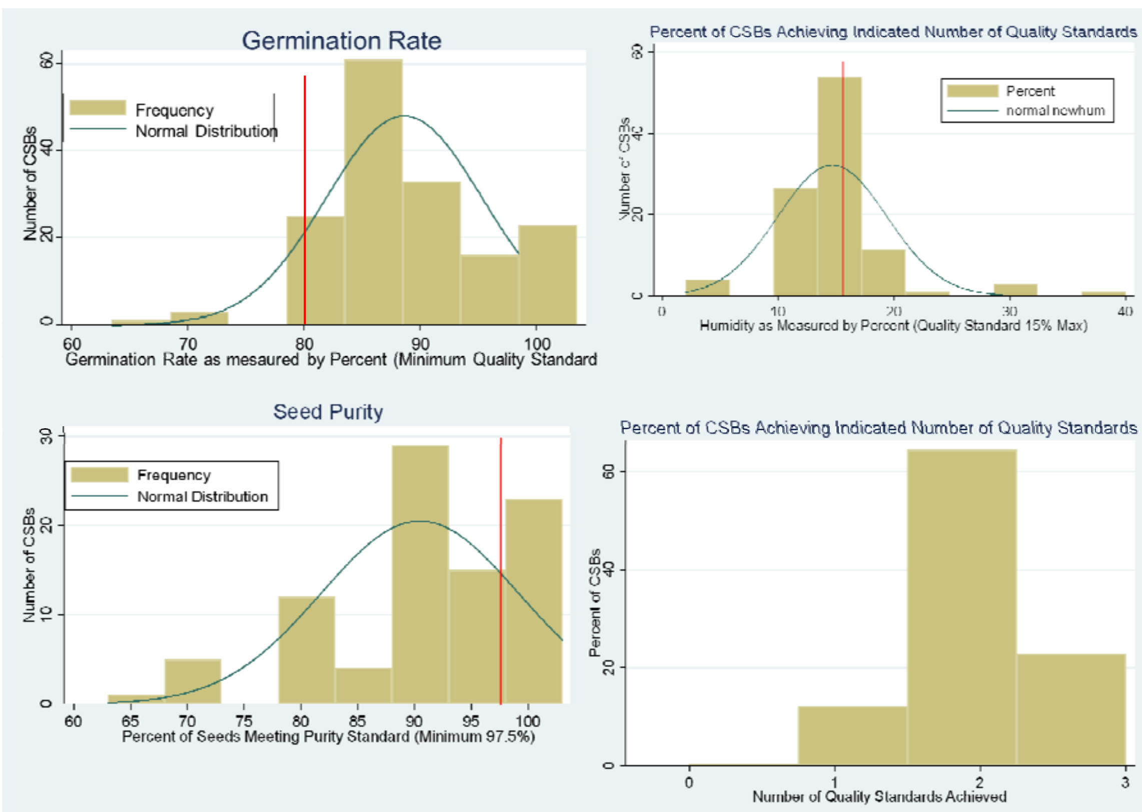
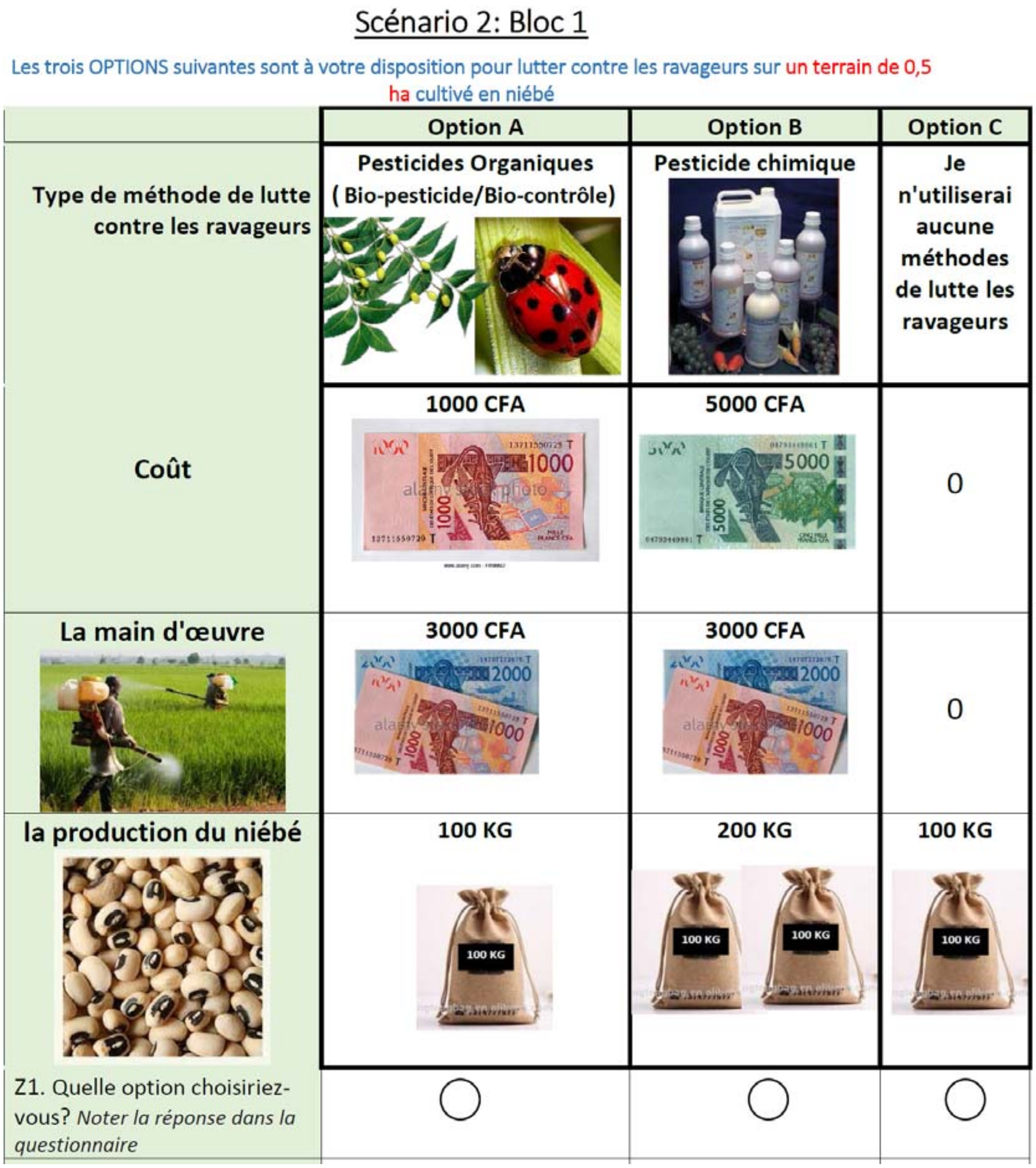


Figure 6. Example of a choice set used in the choice experiment, Burkina Faso



Scénario 2: Bloc 1

Les trois OPTIONS suivantes sont à votre disposition pour lutter contre les ravageurs sur un terrain de 0,5 ha cultivé en niébé

	Option A	Option B	Option C
Type de méthode de lutte contre les ravageurs	Pesticides Organiques (Bio-pesticide/Bio-contrôle)	Pesticide chimique	Je n'utiliserai aucune méthodes de lutte les ravageurs
Coût	1000 CFA	5000 CFA	0
La main d'œuvre	3000 CFA	3000 CFA	0
la production du niébé	100 KG	200 KG	100 KG
Z1. Quelle option choisiriez-vous? *Noter la réponse dans la questionnaire*	○	○	○

Table 1. Men and women farmers' willingness to pay for quality seed of bean varieties with preferred traits: Results of the farmer survey in western highlands of Guatemala, 2015

		Men	Women	All
Number of farmers		*313*	*236*	*549*
Willingness to pay for quality seed of bean varieties with preferred traits indicated in Figure 1 (Quetzales/lb)	*mean*	5.98	6.14	6.06
	(sd)\a	(2.94)	(2.37)	(2.68)

\a Standard deviation are reported in the parenthesis

Table 2: Impact of legume technologies on crop production, income and household food security/dietary diversity indicators: Preliminary results using nationally representative sample of legume growing households in Uganda

Pathways	Outcome Variables	Main explanatory Variables: Cereal leg-inter	Legume-oth inter	Cereal leg-Rota	Legume-oth Rota	Legume-mono
Pooled OLS Model						
Crop Income	Net crop Income	(+) sig	(+) sig	nonsig	(+) sig	nonsig
Crop production	Calories produced/capita/day	(+) sig	(+) sig	(+) sig	(+) sig	nonsig
	Protein Produced/capita/day	(+) sig	(+) sig	(+) sig	(+) sig	nonsig
Food Security & Nutrition Indicators \a	MAHFP	nonsig	nonsig	nonsig	nonsig	nonsig
	FCS	nonsig	(+) sig	nonsig	nonsig	(-) sig
	Dietary Diversity	(+) sig	(+) sig	nonsig	(+) sig	(-) sig
Fixed effects Model						
Crop Income	Net crop Income	nonsig	(+) sig	(+) sig	nonsig	(+) sig
Crop production	Calories produced/capita/day	(+) sig	(+) sig	(+) sig	(+) sig	nonsig
	Protein Produced/capita/day	(+) sig	(+) sig	(+) sig	(+) sig	(+) sig
Food Security & Nutrition Indicators \a	MAHFP					nonsig
	FCS	nonsig				nonsig
	Dietary Diversity					(-) sig

Source: Authors analysis using Uganda LSMS dataset (2009, 2011 and 2013)
\a Definitions of indicators used: **MAHFP** (Months of Adequate Household Food Provisioning) measures the number of months a household had adequate level of food consumption**; FCS** (Food Consumption Score) score represents dietary diversity, food frequency, and relative nutritional importance of different food groups; **Dietary Diversity score** measures number of food groups (out of 12) consumed by the household over the past 7 days (this is similar to HDDS, but the reference period is past 7 days as data for past 24 hours were not captured in the LSMS dataset).

Table 3. Bean yield (kg/ha) from double blind demonstrative field experiments managed by farmers and farmer ranking of plots during harvest stage, Nicaragua

Village ID	Village	Yield (kg/ha, standardized at 14% moisture)			
		Certified seed (Plot circle)	Apta seed (Plot square)	Recycled (Plot triangle)	Average
A1	Santa Rosa	1,821	2,047	1,472	1,780
A2	El Bramadero	1,377	1,696	1,245	1,439
A3	El Horno	1,004	1,419	1,215	1,213
A4	Matapalo	495	570	675	580
A5	Moropoto	2,236	1,895	2,079	2,070
A6	El Porcal	358	655	456	490
B2	Susuli	944	1,543	1,693	1,393
B3	Las Mesas Sur	2,457	2,512	2,615	2,528
B4	Ojo de Agua	312	410	335	352
B6	La Chichigüa	728	1,029	844	867
Average yield\a		**1,173.2 b**	**1,377.6 a**	**1,262.9 ab**	
Percentage of farmers giving the BEST plot rating to plots planted with a given seed (average across all villages)		**11%**	**78%**	**10%**	

Source: Farmer managed field experimental data (Nicaragua willingness to pay study, 2017)
\a Mean with a different letter imply they are statistically significantly different at the 10% level

Table 4. Farmers' BDM WTP (Córdobas/lb) by seed type and biofortification information

Details	Biofortification Information		p-value	Total
	NO	YES		
Average WTP (C$/lb) for:				
Apta Seed	23.39	20.58	0.175	22.0
Certified Seed	17.03	17.37	0.886	17.2
Recycled Grain	17.69	16.01	0.541	16.8
Average Premium (%) for:				
Apta Seed	226.23	212.17	0.498	218.8
Certified Seed	165.81	180.78	0.531	173.8
Recycled Grain	169.79	169.54	0.992	169.7
Number of observations	**112**	**119**		**231**

Table 5. Descriptive Statistics of CSBs in Nicaragua (N=180)

	Mean	Std. dev.
Years of Survival (Years)*	2.36	1.50
Yield Potential (qq/mz)	15.77	8.85
Repayment Rate (%)	0.43	0.39
Received Seed Marketing Training (% Yes)	0.33	0.47
Beneficiaries per Manzana (farmers)	26.38	21.54
Number of Silos owned	2.19	1.97
President over 31 years (% Yes)	0.91	0.29
President is male (% Yes)	0.88	0.32
Type of CSB (% Yes)		
Classic	0.45	
Parceled	0.36	
Individual	0.19	
Travel time to market (Minutes)	28.04	23.74
Meeting Minuets Recorded (% Yes)	0.51	0.50
Access to Backpack Sprayer (% Yes)	0.52	0.50
Received CSB Formation and Operations training (% Yes)	0.76	0.43
Seed plots belong to CSB member (% Yes)	0.63	0.48
CSB members that are immediate family of each other (%)	0.28	0.31
Access to draught animal to pull, plough or cart (% Yes)	0.68	0.47
Region (% Yes)		
Centro Norte	0.24	
Centro Sur	0.25	
Las Segovias	0.20	
Pacifico Norte	0.18	
Pacifico Sur	0.13	

Source: Survey of CSBs in Nicaragua, baseline (2012) and follow-up survey (2017)
\a Survival means CSBs that are still functioning

Table 6: Top three reasons for ending the CSB as reported by CSBs surveyed in Nicaragua, 2017

N=61	Mean	Std. deviation
Reason for Ending CSB (% Yes)		
Impacts of weather (damaged crops)	0.41	0.50
INTA no longer supported the CSB	0.33	0.47
Internal member disagreements on CSB decisions	0.30	0.46
No more registered seed of preferred varieties	0.26	0.44
High cost of producing APTA seed	0.23	0.42
Change of INTA extension agent	0.11	0.32
Low cost recovery (low seed loan repayment)	0.11	0.32
Lack of equipment or land	0.10	0.30
No demand for APTA seed in village	0.08	0.28
Poor seed or not adapted to local conditions	0.08	0.28
No working capital	0.07	0.25
CSB focused on other activities	0.05	0.22
Low quality seed produced	0.05	0.22
Not enough training	0.05	0.22
Issues with INTA extension agent	0.03	0.18
Lack of experience	0.02	0.13

Source: Survey of CSBs in Nicaragua, follow-up survey (2017)
Note: Each CSB could give up to three reason, thus percentages don't add to 100%.

Table 7: Summary of farmer interviews conducted and seed samples collected in Haiti by Department

	Interviews			Seed Samples	
Departments	**Nationally representative sample (selected from USAI farmer list)**	**BTD Farmers**	**TOTAL Farmers Interviewed**	**Number of Farmers Providing Seed Samples**	**Total Seed Samples**
Ouest	132	0	132	65	79
Sud'Est	62	0	62	39	44
Nord	56	62	118	43	46
Nord'Est	39	117	156	36	48
Artibonite	128	109	237	57	77
Centre	74	0	74	69	93
Sud*	66	0	66	30	33
Grand'Anse*	73	0	73	26	26
Nord'Ouest	26	0	26	8	16
Nippes	31	0	31	16	17
Total	687	288	975	389	479

Table 8: Type of Bean Varieties Planted by farmer in Haiti, by type of farmer sample, 2016-17

			BTD Beneficiaries		Nationally representative sample	
Bean Color	**All**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Black	921	0.719	290	0.713	631	0.722
White	114	0.089	58	0.143	56	0.064
Red	80	0.062	17	0.042	63	0.072
Other	166	0.130	42	0.103	124	0.142
Total	1281		407		874	

Source: Haiti bean farmer survey, 2016-17

Feed the Future Innovation Lab for Collaborative Researchon Grain Legumes

Report on the Achievement of "Milestones of Progress"

(For the Period: October 1, 2016-- March 31, 2017)

This form should be completed by the U.S. Lead PI and submitted to the MO by April 1, 2017

Project Title: **SO4.1 Impact Assessment of Dry Grain Pulses CRSP investments in research, institutional capacity building and technology dissemination for improved program effectiveness**

	Abbreviated name of institutions																	
	MSU			Institution 2			Institution 3			Institution 4			Institution 5			Institution 6		
	Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved		Target	Achieved	
Milestones by Objectives	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *	4/1/17	Y	N *
	(Tick mark the Yes or No column for identified milestones by institution)																	
Objective 1	**Provide technical leadership in the design, collection and analysis of data for strategic input and impact evaluation**																	
1.1 Publish a working paper based on Guatemala baseline da	X		X	0			0			0			0			0		
1.2 Complete a manuscript based on LSMS data analysis	0			0			0			0			0			0		
1.3	0			0			0			0			0			0		
1.4	0			0			0			0			0			0		
1.5	0			0			0			0			0			0		
Objective 2:	**Conduct ex ante and ex post impact assessments**																	
2.1 Data analysis completed for the Ghana WTP study	X	X		0			0			0			0			0		
2.2 Field experiments established for WTP study in Nicaragu	X	X		0			0			0			0			0		
2.3 Thesis based on Ghana WTP study completed	0			0			0			0			0			0		
2.4 Manuscript based on WTP field experiments in Nicaragua	0			0			0			0			0			0		
2.5 Endline survey data collection in Burkina Faso completed	X	X		0			0			0			0			0		
2.6 Impact evaluation report / manuscipt for the biocontrol stu	0			0			0			0			0			0		
2.7 Manuscript based on CSB case study completed	0			0			0			0			0			0		
2.8 Data analysis of farm surveys in Haiti completed	X		X	0			0			0			0			0		
2.9 Manuscript based on Haiti adoption study completed	0			0			0			0			0			0		
Objective 4:	**write objective here**																	
4.1	0			0			0			0			0			0		
4.2	0			0			0			0			0			0		
4.3	0			0			0			0			0			0		
4.4	0			0			0			0			0			0		
4.5	0			0			0			0			0			0		
Name of the PI reporting on milestones by institution	Mywish Maredia			PI name			PI name			PI name			PI name			PI name		

Name of the U.S. Lead PI submitting this Report to the MO: Mywish Maredia

Signature **Date**

** Explanation for not achieving the milestones.*

1.1: Currently doing further analysis and report writing. A Staff paper will be published by May.

2.8: Due to hurricane Mathew last year, the survey in Grand Anse and South departments were postponed till March. The data collection in these hurricane affected departments was just concluded this week. Analysis will be completed by September.

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes
REVISED PERFORMANCE INDICATORS / TARGETS SPREADSHEET for FY 14, FY 15, FY16, and FY 17

Project NSO4.1

Institution 6 Name (one sheet per instittion):

Indic. number	Output Indicators	FY 15 Actual	FY 16 Target	FY 16 Revised	FY 16 Actual	FY 17 Target	FY 17 Revised	FY 17 Actual	FY18 Target	FY 18 Revised	FY 18 Actual
		2014 - Septemb	(October 1, 2015 - September 30, 2016)			(October 1, 2016 - September 30, 2017)			(Oct 1, 2017 - Nov 30, 2017)		
1	4.5.2(6) Degree Training: Number of individuals who have received degree tr	0	1	1	4		1	2	0	0	0
	Total number by sex	0	1	1	2		1	2	0	0	0
	Number of women	0	1	1	1		0				
	Number of men	0	0	0	1		1	2			
	Total number by New/continuing	0	1	1	2		1	2	0	0	0
	New	0	1	1	2		0				
	Continuing	0	0	0	0		1	2			
2	4.5.2(7) Short-term Training: Number of individuals who have received short-	0	0	0	0	0	15	19	0	0	0
	Total number by sex	16	15	15	0	0	15	19	0	0	0
	Number of women	4	5	5	0	0	5	1			
	Number of men	12	10	10	0	0	10	18			
	Numbers by Type of individual						15	19	0	0	0
	Producers	0	0	0	0	0	0	0	0	0	0
	Number of women										
	Number of men										
	People in government	16	15	15	0	0	15	19	0	0	0
	Number of women						5	1			
	Number of men						10	18			
	People in private sector firms	0	0	0	0	0	0	0	0	0	0
	Number of women										
	Number of men										
	People in civil society	0	0	0	0	0	0	0	0	0	0
	Number of women										
	Number of men										
7	4.5.2(39) Number of new technologies or management practices in one of the following phases of development: (Phase I/II/III)										
	Phase 1: Number of new technologies or management practices under research as a result of USG assistance	0	0	0	0	0	0				
	Phase 2: Number of new technologies or management practices under field testing as a result of USG assistance	0	0	0	0	0	0				
	Phase 3: Number of new technologies or management practices made available for transfer as a result of USG assistance	0	0	0	0	0	0				

Notes:

These indicators are developed under the Feed the Future Monitoring System. Please provide 'total' numbers and also disaggregate where applicable. Just providing 'totals' will not be approved.

This table corresponds to the Feed the Future Performance Indicators data collection sheet under the FTFMS system. Where an indicator does not apply to the type of work done under the project, leave it blank.

Please follow the indications in the Legume Innovation Lab Indicators Handbook that will be provided to you by the Management Office. Contact Mywish Maredia (maredia@anr.msu.edu) for further information.

There is additional guidance on the USAID/Microlinks website: http://agrilinks.org/sites/default/files/resource/files/FY14%20FTFMS%20Guidance_2.pdf

** Short term training targets not achieved because of significant delays in making funds available to local partners in Haiti to do the training.

XIII. Associate Award Research Project Reports

i) MASFRIJOL

Associate Award by the USAID Mission to Guatemala to Michigan State University (AID-OAA-LA-14-00005) (April 1, 2014 – March 31, 2018), under the Feed the Future Innovation Lab for Collaborative Research on Grain Legumes Leader Award.

(1) Project Description

This Associate Award seeks to enhance the production and consumption of common bean, a nutrient rich food, in the Western Highlands of Guatemala. This region is a focus of the USAID Mission to Guatemala's Feed the Future Initiative because of the high incidence of under-nutrition and child stunting among the Mayan populations. Interventions are being implemented that will provide smallholder farmers with access to quality seed of high yielding improved black bean varieties, technologies to enable household storage of bean grain, and education for rural Mayan women and men on the nutritional and health value of eating beans. The ultimate objective is to enhance the food and nutritional security of Mayan households through increased access to and consumption of beans.

(2) Collaborators

- Fundación para la Innovación Tecnológica, Agropecuaria y Forestal (FUNDIT), Guatemala
- Instituto de Ciencia y Tecnología Agrícola (ICTA), Guatemala
- Ministerio de Salud Pública y Asistencia Social (MSPAS), Guatemala
- Centro de Comunicación para el Desarrollo (CECODE), Guatemala
- Implementing partners in the USAID/Guatemala Mission's Western Highlands Initiative Program

(3) Achievements in FY 2017

- An additional 3,457 households received 5 lbs of quality seed of an improved black bean variety, bringing the total number of beneficiary families reached since 2014 to approximately 35,000.
- Sustainable access to quality seed (QDS) is being achieved through the establishment of Community Seed Depots (CDS), a form of community based seed multiplication. In FY 17, an additional 48 new CDSs were established bringing the total of functioning CDS to 80 in the Western Highlands of Guatemala. These CDS sold bean seed to >1,600 farmers for planting in FY 2017.
- CDSs sold locally produced seed at an average of $1.26 per lb which is 20 to 100% above grain prices in local markets, indicating that seed multiplication can be a profitable endeavor for smallholder farmers in the region.
- Nutrition education classes were provided to 10,182 beneficiaries in FY 17, bringing to total number participants in nutrition education classes to 22,881 for the project since its inception. In addition, 4,840 participated in bean recipe demonstration and cooking classes.
- Farmer testimonials suggest that they are experiencing high yields (up to 2

MT/ha) and improved household security as a result of planting quality seed of the introduced black bean varieties.

(4) Capacity Building

No additional cross-training of Ministries of Agriculture and of Public Health on nutrition and bean crop production were provided by MASFRIJOL in FY 2017, since it was the final year of the project.

(5) Lessons Learned

The performance and effectiveness of MASFRIJOL was enhanced by collaborating and coordinating activities with WHIP and other development partner organizations/programs working in the target FTF region (Western Highlands) of Guatemala.

ii) Legume Scholars Program

Associate Award by the USAID Office of Agriculture Research and Policy, Bureau of Food Security, Washington to Michigan State University (AID-OAA-LA-17-00002) under the Feed the Future Innovation Lab for Collaborative Research on Grain Legumes Leader Award. The performance period is April 1, 2017 – November 30, 2019 with total estimated funding of $750,000.

(1) Project Description

The Legume Scholars Program (LSP) was established in 2014 as a new program to support PhD degree training of promising young scientists from developing countries to build future international research capacity in grain legumes. Initially, the scholarship program was jointly supported by the CGIAR Research Program on Grain Legumes, and USAID's Feed the Future Innovation Labs for Collaborative Research on Grain Legumes (Legume Innovation Lab) and Peanut Productivity and Mycotoxin Control (Peanut and Mycotoxin Innovation Lab).

Since the Legume Innovation Lab Management Office had assumed administrative responsibility for the LSP program, it was necessary for USAID to establish a new Associate Award so that MSU could continue in this role after the LIL program ends (Nov. 30, 2017).

Objectives of the Legume Scholars Program are:

- To build human research capacity of national agriculture research institutions in developing countries in applying cutting-edge science to address future challenges and opportunities of the legume sector in developing countries.
- To facilitate greater collaboration in research between the CGIAR and the USAID Innovation Lab legume scientists through joint supervision of graduate student research projects.
- To attract a new generation of scientists prepared to address complex global challenges in sustainable ways to achieve agriculture development goals in legume producing countries around the world.

(2) Collaborators

The following sponsored Legume Scholar students are enrolled in PhD graduate programs at the following universities.

- Aggrey Gama, Food Science, University of Georgia
- Rosemary Bulyaba, Agronomy, Iowa State University
- Isaac Osei-Bonsu, Plant Physiology, Michigan State University
- Susan Moenga, Plant Genetics, University of California Davis
- Pacem Kotchofa, Agriculture Economics, Kansas State University

(3) Achievements in FY 2017

As of April 1, 2017, five outstanding students (three female and two male) are enrolled in PhD level graduate programs at five U.S. universities with sponsorship from the LSP. Each student is mentored by an Innovation Lab PI, plus a CGIAR scientist has been selected to serve of each student's graduate guidance committee. In FY 2017, all five scholars made acceptable progress toward completion of their PhD programs, which are projected to end in October 2019.

(4) Capacity Building

The scholars will enhance the grain legume research capacity of institutions in their home countries, four of which are Future Focus Countries: Ghana, Kenya, Uganda, and Malawi. A fifth student is from Benin and her work will have regional implications through the IITA research center in Cotonou. The broad disciplinary focus of the graduate programs, including food science, agronomy, plant physiology, plant genetics and agricultural economics, ensures that African institutions will be able to address a broad range of constraints and opportunities facing the grain legume sector in the future.

XIV. Human and Institutional Capacity Development

i. Short-term training

In the table below, researchers on our projects conducted eleven short-term training programs involving 886 trainees, including research staff, farmers, private sector stakeholders and others. The programs were held at national level or in the US for specific host country nationals. Topics ranged from using mobile phone apps to collecting data with tablets and using the PhotosynQ platform. Stakeholders in bean value were brought together in different regions of Zambia and Malawi for training on strategic alliances, leading to the creation of the Beans for Health and Wealth Association of Zambia. Approximately 45 percent of the trainees were women.

Table 1 Legume Innovation Lab short-term training programs during FY2017

Country of Training	Brief purpose of Training	Who was trained	Male trainees	Female trainees	Total trainees
	National Programs				
Zambia	Training ZARI technicians on use of PhotosynQ Platform	Zambian Agricultural Research Institute (ZARI) research technicians	2	2	4
Uganda	Use of PhotosynQ to phenotype drought	Makerere University/NARO	12	8	20
Uganda	New data collection tools using tablets	Makerere University/NARO	12	8	20
Burkina Faso	Training on use of IPM	Cowpea farmers	70	75	145
Niger	Training on use of IPM	Cowpea farmers	55	120	175
Uganda	Development and use of mobile phone app	Mozambican and Uganda researchers and technicians	75	75	150
USA	Training on development and use of soil-landscape maps	NARI and Makerere researchers (Uganda)	2	0	2
Malawi	Training on strategic alliances among industry stakeholders to enhance performance and income: 3 regional training workshops	Bean and cowpea industry stakeholders (processing, trading and producing private sector agent; civil society and public sector agents and researchers	112	62	174

Country of Training	Brief purpose of Training	Who was trained	Male trainees	Female trainees	Total trainees
Zambia	Training on strategic alliances among industry stakeholders to enhance performance and income: 3 regional training workshops	Bean and cowpea industry stakeholders (processing, trading and producing private sector agent; civil society and public sector agents and researchers	125	50	175
USA	Good clinical practice for researchers in nutrition	Malawian researchers	1	1	2
Haiti	Bean sample collection and vendor information collection systems	Haitian Ministry of Ag technicians	18	1	19
Total			484	402	886

ii. Long-term training

Long-term degree training is a fundamental part of the collaborative research sponsored through the Legume Innovation Lab for it ensures a new generation of scientists in the developing world, while connecting them with a worldwide network of researchers. Based on research assistantships, the degree candidates are research partners, becoming professionals as they learn the tools of the trade and advance their degrees. The relationships that they form during training provide the base for future research collaborations. Our long term trainees are also included in the Research Conferences held in Africa and elsewhere, further extending their relationships and exposure to cutting-edge research across the globe.

As shown in Table 2, during FY17, Legume Innovation Lab projects fully or partially funded 50 female students and 64 male students, for a total of 114 students in university degree programs, including the five Legume Scholars indicated in section VI. Of those students in this degree training, 64% were studying at African universities, 18% at Latin American Universities, and 17% in US universities (one student in Finland included). A total of 37 students completed their degree programs within FY2017 and 77 are continuing students who have obtained additional funding to complete their programs in FY2018 and beyond. Many of the continuing students will finish in Dec 2017. Among the students, the majority (75%) are African, 25% from the Caribbean and Central America. Most students are only partially funded under LIL, with just research costs or other aspects related to their training program covered. This enables leveraging of training resources at the universities. There are Bachelors students, mainly at EAP-Zamorano in Honduras, receiving only partial funding, while 52% of students are pursing MS degrees and are in the US, Central America, and West, Eastern and Southern Africa. The 31 PhD students are mainly studying in the US and Africa. Table 3 lists the students with additional information.

Table 2 Summary Table on Long Term Degree Students *

Students by categories	Number	%		Number	%
Sex			**Nationality**		
Female	47	42	African	83	75
Male	64	58	Latin American/Caribbean	28	25
Degree program			**Location of University**		
BS	29	26	Sub-Saharan Africa	70	63
MS	51	46	Latin America	21	19
PhD	31	28	US**	20	18
Degree Program Completed in FY2017 or Continuing?					
Completed	34	31			
Continuing	77	69			
* Excludes support for US students.					
** One student in Finland					

Table 3 Legume Innovation Lab long-term training program participants during FY2017

Student Last Name	First Name	Sex	University	Degree	Major	Grad Date	Degree granted (Y/N)	Home Country
Abdoulaye	Ousseina	F	Univ Maradi	PhD	Entomology	Dec-18	N	Niger
Abdourahmane	Maimouna	F	Univ Maradi	PhD	Entomology	Dec-18	N	Niger
Agbaka	Fiacre	M	Intl Institute of Tropical Agric.	MS	Entomology	Dec-16	y	Benin
Agyeman Duah	Godfred	M	UDS, SARI/Ghana, University of California	MS	Biotechnology	Jun-18	N	Ghana

Student Last Name	First Name	Sex	University	Degree	Major	Grad Date	Degree granted (Y/N)	Home Country
			Riverside					
Ahongnonon	Laurent	M	Intl Institute of Tropical Agric.	MSc	Entomology	Dec-16	Y	Benin
Alarcon	Ivan	M	EAP Zamorano, Honduras	BS	Agronomy	Dec-17	N	Ecuador
Alizanou	Mesmin	M	Intl Institute of Tropical Agric.	MSc	Entomology	Dec-16	Y	Benin
Amadou	Kader Djibo	M	Univ Maradi	BSc	Entomology	Dec-16	Y	Niger
Amosah	Deborah Anobil	F	K.Nkrumah Univ., Kumasi, Ghana	BS	Agriculture	Dec-16	Y	Ghana
Arroba	Klever	M	EAP Zamorano, Honduras	BS	Agronomy	Nov-17	N	Ecuador
Arteaga	Fatima	F	EAP Zamorano, Honduras	BS	Agronomy	Dec-17	N	El Salvador
Asare	Akosua Addai	F	Univ Devlopment Studies, Tamale	BS	Entomology	Dec-16	Y	Ghana
Attamah	Patrick	M	UDS, SARI/Ghana, University of California Riverside	MS	Plant Breeding	Dec-16	Y	Ghana
Attamah	Patrick	M	UDS, SARI/Ghana, University of California Riverside, Kirkhouse Trust	PhD	Plant Breeding	Dec-21	N	Ghana
Avaroma	Fatima	F	EAP Zamorano, Honduras	BS	Agronomy	Dec-17	N	Bolivia
Banda	Dinah Tuwanje	F	LUANAR, Malawi	MSc	Agricultural Economics	Dec-16	Y	Malawi
Besilla	Maria	F	EAP Zamorano, Honduras	BS	Agronomy	Nov-17	N	Ecuador
Biaou	Eustache	M	Intl Institute of Tropical Agric.	MS	Social Sciences	Dec-18	N	Benin
Boube	Nafissatou Illa	F	Univ Maradi	BSc	Entomology	Dec-16	Y	Niger
Brinette	Senan Ange	F	Intl Institute of Tropical Agric.	MS	Entomology	Jul-17	Y	Benin
Bulyaba	Rosemary	F	Iowa State	PhD	Agronomy	Sep-	N	Uganda

Student Last Name	First Name	Sex	University	Degree	Major	Grad Date	Degree granted (Y/N)	Home Country
			University			19		
Burgos	Kevin	M	EAP Zamorano, Honduras	BS	Agronomy	Dec-17	N	Ecuador
Bwambale	Naboth	M	Iowa State University	PhD	Sustainable Agriculture	May-19	N	Uganda
Cabana	Belky	M	EAP Zamorano, Honduras	BS	Agronomy	Nov-17	N	Peru
Campos	Priscila	F	EAP Zamorano, Honduras	BS	Agronomy	Nov-17	N	El Salvador
Chanaluisa	Jorge	M	EAP Zamorano, Honduras	BS	Agronomy	Nov-17	N	Ecuador
Chengula	Ocran	M	Sokoine University, Tanz.	MS	Agricultural Economics	Dec-17	N	Tanzania
Chipandwe	Susan	F	University of Zambia	MS	Plant breeding and seed systems	Sep-17	N	Zambia
Chisusu	Dorothy	F	LUANAR, Malawi	MSc	Agribusiness Mgmt	Sep-17	Y	Malawi
Chitete	Moses	M	LUANAR, Malawi	MSc	Agricultural Economics	Sep-17	Y	Malawi
Dabre	Elisee	F	Univ Ouagadougou	PhD	Entomology	Dec-19	N	Burkina Faso
Daza	Daniel	M	EAP Zamorano, Honduras	BS	Agronomy	Dec-17	N	Ecuador
Dera	Mariam	F	Univ Ouagadougou	PhD	Entomology	Dec-18	N	Burkina Faso
Diangar	Mouhamadou Moussa	M	WACCI	PhD	Plant Breeding	Aug-19	N	Senegal
Didier	Joseph	M	University of Puerto Rico	MS	Plant pathology	May-18	N	Haiti
Divala	Oscar	M	Univ of Malawi School of Medicine	PhD	Epidemiology	Jun-18	N	Malawi
Drabo	Edouard	M	Univ Ouagadougou	MSc	Entomology	Jul-17	Y	Burkina Faso
Dramadri	Isaac	M	Michigan State University	PhD	Plant Breeding, Genetics and Biotechnology	May-18	N	Uganda
Dzimbiri	Billy Mark	M	LUANAR, Malawi	MSc	Agribusiness Mgmt	Sep-17	N	Malawi
Espinoza	Edhinson	M	EAP Zamorano, Honduras	BS	Agronomy	Dec-17	N	Ecuador
Espinoza	Henry	M	EAP Zamorano, Honduras	BS	Plant Science	Dec-17	Y	Ecuador

Student Last Name	First Name	Sex	University	Degree	Major	Grad Date	Degree granted (Y/N)	Home Country
Felicien	Zida Serge	M	Univ Ouagadougou	PhD	Plant Breeding	Dec-19	N	Burkina Faso
Gama	Aggrey	M	UGA	PhD	Food Science and Technology	Sep-19	N	Malawi
Ganiu	Mohammend Abdul	M	UDS, SARI/Ghana, University of California Riverside	MS	Agronomy	Mar-17	Y	Ghana
Gavilanes	Segundo	M	EAP Zamorano, Honduras	BS	Agronomy	Nov-17	N	Ecuador
Gonda	Rakia	F	Univ Maradi	BSc	Entomology	Dec-16	N	Niger
Honfonga	Judith	F	Intl Institute of Tropical Agric.	MS	Entomology	Jul-17	Y	Benin
Imorou	Nazyath	F	Intl Institute of Tropical Agric.	MSc	Entomology	Dec-17	N	Benin
Issa	Soumaila Abdou	F	Univ Maradi	BSc	Entomology	Dec-16	Y	Niger
Issaka	Haouaou	F	Univ Maradi	MSc	Entomology	Dec-16	N	Niger
Jackson	Jacob	M	Sokoine University, Tanz.	MS	Agricultural Economics	Jun-18	N	Tanzania
Jama	Nandi Nomsa	F	University of Zambia	MS	Agricultural Economics	Feb-18	N	Zambia
Kaimila	Yankho	F	Univ of Malawi School of Medicine	PhD	Epidemiology	Jun-18	N	Malawi
Karidiatou	Gnankambary	F	University Ouagadougou; INERA	PhD	Plant breeding	Dec-19	N	Burkina Faso
Kasanda	Ednah	F	Kansas State University	MS	Agricultural Economics	Jun-17	Y	Zambia
Katuuramu	Dennis	M	Michigan State University	PhD	Plant Breeding, Genetics, and Biotechnology	Dec-17	N	Uganda
Kavishe	Basil Evarist	M	Makerere Univ, Uganda	MS	Plant Breeding	Dec-17	N	Tanzania

Student Last Name	First Name	Sex	University	Degree	Major	Grad Date	Degree granted (Y/N)	Home Country
Kenamu	Edwin	M	LUANAR, Malawi	MSc	Agribusiness Mgmt	Sep-17	Y	Malawi
Kotchofa	Pacem	F	Kansas State University	PhD	Agricultural Economics	Sep-19	N	Benin
Kpongbe	Hilaire	M	Intl Institute of Tropical Agric.	PhD	Entomology	Dec-18	N	Benin
Kwesi	Samuel Abekah	M	UDS, Ghana	BS	Entomology	Dec-17	N	Ghana
Kyebogola	Stewart	M	Makerere Univ, Uganda	MS	Soil Science and Crop Production	Mar-18	N	Uganda
Kyomuhendo	Prossy	F	Makerere Univ, Uganda	MS	Soil Science and Crop Production	Jan-17	Y	Uganda
Leandre	Poda Saadon	M	KNUST, SARI/Ghana, University of California Riverside	MS	Plant Breeding	Dec-16	Y	Burkina Faso
Lifeyo	Yanjanani	M	LUANAR, Malawi	MSc	Agribusiness Mgmt	Sep-17	Y	Malawi
Lo	Sassoum	F	University of California Riverside	MS, PhD	Plant breeding and genetics	Jun-18	N	Senegal
Lungu	Charles	M	Sokoine University, Tanz.	MS	Agricultural Economics	Nov-16	N	Tanzania
Mahule Elyse Alladassi	Boris Mahule Elyse	M	Makerere Univ, Uganda	MS	Plant Breeding	Feb-17	Y	Benin
Maldonado	Carlos	M	North Dakota State University	MS	Plant breeding	Dec-17	N	Guatemala
Martinez	Hector	M	University of Puerto Rico	MS	Plant breeding	Jul-17	y	Guatemala
Martinez	Jose	M	EAP Zamorano, Honduras	BS	Plant Science	Dec-17	Y	El Salvador
Matege	Jafali	M	Makerere Univ, Uganda	MS	Ag Extension Education	Aug-18	N	Uganda
Mayaki	Rahina Souley	F	Univ Maradi	BSc	Entomology	Dec-16	Y	Niger
Mbamba	Austin	M	KSU (Sandwich in Malawi)	MS	Agribusiness Mgmt	May-18	N	Malawi
Mbaso	Marvin	M	KSU (Sandwich in Malawi)	MS	Agribusiness Mgmt	May-18	N	Malawi

Student Last Name	First Name	Sex	University	Degree	Major	Grad Date	Degree granted (Y/N)	Home Country
Medard	Elizabeth	F	Sokoine University, Tanz.	MS	Agricultural Economics	Jun-18	N	Tanzania
Mokongu Moenga	Susan	F	UC, Davis	PhD	Plant biology	Sep-19	N	Kenya
Monserrate	Luis	M	EAP Zamorano, Honduras	BS	Plant Science	Dec-17	Y	Ecuador
Montcho	Nicolette	F	Intl Institute of Tropical Agric.	MSc	Entomology	Jul-17	Y	Benin
Montejo	Luz de Maria	F	North Dakota State University	MS	Plant Breeding	Dec-17	N	Guatemala
Msukwa	Wupe	M	LUANAR, Malawi	MSc	Agricultural Economics	Jan-17	Y	Malawi
Nambe	Bintou	F	INERA	PhD	Entomology	Dec-17	N	Burkina Faso
Ndeve	Arsenio	M	University of California Riverside	PhD	Plant pathology & genetics	Dec-17	Y	Mozambique
Ngoma	Theresa	F	LUANAR, Malawi	MS	Food Science & Tech.	Jun-17	Y	Malawi
Nunez	Juan	M	EAP Zamorano, Honduras	BS	Plant Science	Dec-17	Y	Honduras
Odogwu	Blessing	F	Makerere Univ, Uganda	PhD	Plant Breeding	Dec-17	N	Nigeria
Osei--Bonsu	Isaac	M	Michigan State University	PhD	Plant Biology	Sep-19	N	Ghana
Ouedraogo	Adelaide	F	INERA (w/WACCI)	PhD	Plant Breeding	Dec-19	N	Burkina Faso
Ouedraogo	P. Carine	F	INERA	PhD	Entomology	Dec-17	N	Burkina Faso
Ouedraogo	Theodore Y.	M	Univ Ouagadougou; INERA	PhD	Entomology	Jul-17	Y	Burkina Faso
Owusu	Emanuele Yaw	M	SARI/Ghana, University of California Riverside	MS	Plant Breeding	Dec-16	Y	Ghana
Rivera	Katya	F	EAP Zamorano, Honduras	BS	Agronomy	Nov-17	N	Honduras
Rocha	Antonio	M	Univ Hawaii	MS	Agronomy and Tropical soils	Aug-17	N	Mozambique
Rodriguez	Diego	M	University of Puerto Rico	MS	Plant breeding	Jul-17	y	Ecuador
Rodriguez	Iveth	F	University of Puerto Rico	MS	Plant breeding	Jul-17	y	Honduras
Rosas	Andres	M	EAP Zamorano, Honduras	BS	Agronomy	Nov-17	N	Ecuador

Student Last Name	First Name	Sex	University	Degree	Major	Grad Date	Degree granted (Y/N)	Home Country
Rwakalaza	Rameck	M	Sokoine University, Tanz.	MS	Agricultural Economics	Jun-18	N	Tanzania
Sakala	Isabel	F	University of Zambia	MS	Agricultural Economics	Feb-18	N	Zambia
Salgado	Sara	F	EAP Zamorano, Honduras	BS	Agronomy	Dec-17	N	Ecuador
Sidibe	Hamadou	M	Univ Ouagadougou; INERA	PhD	Plant breeding	Dec-19	N	Burkina Faso
Solis	Elisa	F	EAP Zamorano, Honduras	BS	Agronomy	Nov-17	N	Guatemala
Soumabere	Coulibaly	M	Univ Ouagadougou	MS	Plant Breeding	Mar-17	Y	Burkina Faso
Soumaila	Abdou Issa	M	Univ Ouagadougou	PhD	Entomology	Dec-16	N	Niger
Souna	Djibril Aboubakar	M	Intl Institute of Tropical Agric.	PhD	Entomology	Dec-18	N	Benin
Swema	Ezekiel	M	Sokoine University, Tanz.	MS	Agricultural Economics	Jun-18	N	Tanzania
Tapsoba	Flora Addisa	F	KNUST,SARI/Ghana, University of California Riverside	MS	Plant Breeding	Dec-17	N	Burkina Faso
Tetteh-Kubi	Gloria	F	UCC, SARI/Ghana, University of California Riverside	PhD	Agronomy	Dec-18	N	Ghana
Thakwalakwa	Chrissie	F	Tampere Univ of Finland	PhD	Community Health	Jul-17	Y	Malawi
Tobar Pinon	Maria Gabriela	F	North Dakota State University	MS	Plant Breeding and Genetics	Nov-17	N	Guatemala
Zevallos	Enrique	M	EAP Zamorano, Honduras	BS	Agronomy	Nov-17	N	Peru
Zulu	Mabvuto	M	University of Zambia	MS	Agricultural Economics	Jun-18	N	Zambia

iii. Institutional Development

Institutional Capacity Strengthening Awards: The LIL competitively awards funds to host country scientists to strengthen the research capacity on grain legumes at their respective institutions. These funds are greatly appreciated since they provide funding for equipment upgrades or replacement that are critical for research program and which may not have been originally budgeted. In FY2016, the LIL approved $159,138 for 10 of capacity strengthening projects (see Table 3 for details). These projects were implemented during FY2017.

Table 4 Legume Innovation Lab Institutional Capacity Strengthening Projects implemented in FY2017

Beneficiary Host Country Institution	Approved Activity	Total budget recommended by TMAC
ICTA, Guatemala	Rehabilitate parts of drip irrigation system and recondition the seed storage/ germplasm bank	$9,900
University of Zambia, Zambia	Improve irrigation capacity at the University of Zambia research farm	$21,120
Zambia Agriculture Research Institute - ZARI	Upgrading of seed storage facility	$15,250
Escuela Agricola Panamericana Zamorano, Honduras	Purchase of a replacement autoclave, essential piece of equipment for the bean research program to screen for pathogen resistance	$15,800
INERA, Burkina Faso	Enhancing capacity of seed laboratory to test seed, calibrate breeder seed as well as large-scale seed quality testing prior to distribution	$13,000
ISRA, Senegal	Rehabilitation of a screen house to develop capacities in phenotyping	$16,188
CSIR-SARI, Ghana	Rehabilitation of laboratory for culturing and infecting flower thrips at the Manga Station	$17,300
INERA, Burkina Faso	Reconditioning of cowpea insect pest-rearing rooms	$20,020
INRAN, Niger	Lab enhancements to facilitate parasitoid multiplication	$10,560
IIAM, Mozambique, and NARL, Uganda	Identification of options for mobile phone applications (apps) to enhance communication between researchers extension, and farmers, as well as adapting selected technical packages and materials for sharing via apps	$20,000

XV. Innovation Transfer and Scaling Partnerships

i) Plan of Action

The Legume Innovation Lab is primarily a research and capacity strengthening program and does not have significant funding for moving along the research to development continuum. All Legume Innovation Lab projects developed "Impact Pathway Plans", under the guidance of LIL impact specialist Dr. Mywish Maredia, at the inception of each integrated research and capacity strengthening project in FY 2013. These Impact Pathway Plans were an addendum to project documents and used to guide researchers in technology development, transfer and scale up so as to ensure achievement of developmental outcomes. For implementation of project impact pathways, PIs included the development of outreach materials, training videos, and training programs for potential public and private end-users of the technologies. Strategic partnerships with NGOS and civil society stakeholders were an integral part of the value chain project (SO2.2) and conferences were designed to promote networking and advocacy among local bean stakeholders.

ii) Steps taken

In FY 2017, Legume Innovation Lab projects did not directly support technology transfer and scaling up activities, although the research conducted with farmer organizations in Uganda, Mozambique, Honduras and elsewhere, based on Innovation Platforms or other approaches, provide experience and insight into what is needed for farmer adoption. In Zambia and Malawi, stakeholder groups were brought together to create advocacy groups. With the impact assessment research in SO4.1, we further investigate dissemination and adoption, as with farmer willingness to pay for improved or certified seed research in Tanzania and Ghana, setting the stage for dissemination activities.

The MASFRIJOL Associate Award with the Guatemala Mission does have a scaling objective, and works with quality seed of improved varieties to reach farmers in the Western Highlands with extension agents and village fairs. The work integrates nutrition and agriculture and is enabling farm households to have access and use the improved varieties, and builds on the previous research of the national system with the Legume Innovation Lab researchers.

iii) Partnerships made

Partnerships are a foundation of the Legume Innovation Lab approach, making a link between research and scaling. LIL projects develop formal and informal partnerships with NAROs, NGO and private sector organizations with interest in a particular technology and committed to achieving common developmental outcome goals as defined in the LIL project Impact Pathways. The host country partners in SO1.A3 and SO2.1 projects coordinated their research activities with those of the Pan African Bean Research Alliance (PABRA), a network of CIAT supported research institutions in SubSaharan Africa, including the scale up of technologies through Innovation Platforms. EAP-Zamorano (SO1.A4) also developed strong ties both with regional NAROs, farmer organizations and NGOs to facilitate participatory plant (bean) breeding objectives and to systematize the release of new varieties for commercial production and the production of early generation seed to meet national demand.

iv) Technologies ready to scale

There are improved bean varieties released in Central America with bruchid resistance, drought tolerance and other traits valuable. Researchers are responsible for multiplying breeder seed to have foundation seed on hand for seed producers. The SO1.B1 and SO2.1 project have designed and continue to develop animated videos with selected technologies, and these are shared with Innovation Platforms and other farmer fora, and are publicly available.

v) Technologies transferred

Varieties that have been released by the national systems are now in the hands of national public and private sector agents. In most cases, the public sector takes breeder seed and multiplies it to provide foundation seed to seed producers, whether farmer groups, nongovernmental organizations or the private sector. The Legume Innovation Lab's funding is focused on the research and capacity strengthening for varietal development and other aspects.

vi) Technologies scaled

Improved bean varieties have been disseminated in 2016 in Guatemala with the MASFRIJOL Associate Award in the Western Highlands, with our ICTA collaborators in combination with extension and MASFRIJOL staff.

XVI. Environmental Management and Mitigation Plan (EMMP)

In response to negative determinations in the Internal Environmental Examination (IEE) of the Legume Innovation Lab's research portfolio by USAID's Bureau Environmental Officer in FY 2014, the Management Office prepared an Environmental Mitigation and Monitoring Plan (EMMP) for the safe procurement, handling and use of pesticides, fertilizers, microbial inoculants and biologicals in research activities under the Legume Innovation Lab both in host countries and the U.S. The EMMP for LIL was approved by USAID in FY 2015. USAID also provided authorizations for the use of fertilizers and selected pesticides and microbial inoculants and the projected expenditure of USAID funds for procurement and use by subcontracted PIs and institutions through the end of the current project (November 30, 2017). The approved EMMP was included in the modifications to all Legume

Innovation Lab subcontracts with both U.S. and host country institutions along with the FY 2015 obligation of funds. The lists of authorized fertilizers and pesticides were sent via emails to PIs and attached as addendums to the modifications to subcontracts.

Report on mitigation and monitoring activities as per EMMP

Lead and Host Country PIs of Legume Innovation Lab subcontracted projects are responsible for monitoring and determining compliance with the terms for each research activity involving chemical pesticides, fertilizers, microbial inoculants and biologicals in their research activities at the various institutions participating in the program. A review of mitigating and monitoring of the protocols for handling, storage and disposal of these materials are conducted during visits by the LIL PIs. Within FY 2017, the Management Office for the Legume Innovation Lab did not receive any reports from Lead PIs of problems of failure to comply with the EMMP.

XVII. Open Data Management Plan

In the age of electronic resources and emphasis on evidenced based development planning and a global research community, LIL is working to respond to the whole of government mandate ensuring free and open access to quality research data. We have worked with each of the projects to develop their data management plans and those have been reviewed by USAID. Each of the projects is currently editing their Plans with final information and submitting datasets in compliance with USAID guidelines, identifying current open data compliant services. The breadth of disciplinary emphasis across the projects means that there are exciting opportunities for placement of the data sets, and there are new options.

We acknowledge the challenge of making sure that LIL research data and accompanying documentation are available in a readily accessible location and format for potential users. To this end, it is important that each project data set be archived in an appropriate place/library where it will receive high exposure and be easily found by interested scientists. Several of the LIL PIs decided to use DDL as the main repository for their data. Other PIs expressed a desire to identify a data curation site more commonly used by other scientists in their discipline which meets US government ADS 579 requirements. For datasets not based in the USAID Development Data Library (DDL), project researchers will document in DDL where the datasets and documentation can be found.

XVIII. Governance and Management Entity Activity

FY 2017 was the fifth and final fiscal year of the current phase of the Feed the Future Collaborative Research Program on Grain Legumes (Legume Innovation

Lab- LIL) administered by Michigan State University (AID-EDH-A-00-07-00005). Key responsibilities of the Management Office during this fiscal year included the contractual and financial management of ten collaborative integrated research and institutional capacity strengthening projects in thirteen HCs including eleven Feed the Future countries in West Africa, East and Southern Africa and in Latin American and the Caribbean.

On January 18, 2017, Michigan State University (MSU) received modification 11 from USAID, which increased the obligation by $5,688,543.00 bring the total cumulative obligation to the Dry Grain Pulses CRSP (FY 2007-2012) and the Legume Innovation Lab (FY 2013-2017) Leader Award to $38,136,749.00. Of this obligation, $3,705,702.00 was awarded to the Legume Innovation Lab as core program support, and $1,982,841.00 was new funding to support the "Haiti Bean Seed Security Project- *Mwen Gen Pwa*".

The Haiti Bean Seed Security Project was a buy-in to the LIL Leader of $1,982,841.00 by the USAID Mission to Haiti as a relief response to the food insecurity situation caused by Hurricane Matthew in Southwestern Haiti in October 2016. The LIL Management Office at Michigan State University assumed responsibility for implementation of the one-year project (November 1, 2016 to November 30, 2017) with subcontracted partners, the National Seed Service of MARNDR/Haiti, and the InterAmerican Institute for Cooperation in Agriculture (IICA-Haiti).

Since Mwen Gen Pwa is a one year project ending on November 30, 2018, USAID issued a modification (12) to MSU to extend the period of performance period of LIL for an additional two months (until 11/30/2017).

The Mwen Gen Pwa project in Haiti demanded a significant amount of effort by LIL Management Office staff during the first four months of FY 2017 because of the urgency to procure quality seed from international sources of appropriate black bean varieties in sufficient quantities (> 200 MT) and to arrange for the shipment of the seed to Haiti for distribution prior to the first 2017 planting season in January and February 2017. This effort required the establishment of a new subcontract with the InterAmerican Institute for Cooperation in Agriculture (IICA-Haiti), which played a strategic role in coordinating the seed distribution with over 120 community-based organizations in Haiti. The effort was coordinated by Luis Flores at MSU and Reginald Cean in Haiti with administrative support from Angelica Santos (International Contractual and Financial Officer) and Irvin Widders, PI for the project. The MO is pleased to report that the LIL effectively surpassed its deliverable goal of 6,000 beneficiaries by providing quality seed of improved varieties to 11,447 households, plus training and technical assistance to 14,092 persons. A final report of the Mwen Gen Pwa project was presented the USAID Mission in Port au Prince in December 2017.

The focal activity in FY 2017 of the LIL Management Office was the organization and hosting of the 2017 LIL Grain Legume Research Conference on 13 – 18 August 2017 at the Laico Ouaga 2000 Hotel in Ouagadougou, Burkina Faso. The Institut de l'Environnement et des Recherches Agricoles (INERA) – Burkina Faso, an institute of the Centre National de la Recherche Scientifique et Technologique (CNRST), partnered and assisted the LIL MO with planning and local arrangements for the conference in Ouagadougou. The LIL MO wishes to thank Hamidou TRAORE (Director), Joseph BATIENO, Clementine DABIRE and Fousséni TRAORE (LIL PIs) of INERA for their dedicated assistance in making the conference as success.

Since 2017 was the final year of the LIL program, a goal of the conference was to provide a forum for Legume Innovation Lab scientists and collaborators from the United States, Africa, and Latin America and the Caribbean to gather and to present their research findings and technical achievements on edible grain legume crops over the past five years. The thematic foci of the conference was on increasing grain legume productivity; strengthening grain legume value chains; enhancing nutrition, especially among women and children; and improving outcomes of research and capacity strengthening to ensure greater developmental impact.

The LIL Technical Management Advisory Committee (TMAC) along with several volunteer PIs played a critical and valued role in reviewing all abstracts submitted for either oral or poster presentations, assigning accepted papers to thematic sessions and in developing the conference program. The program consisted of four Plenary Oral Sessions with invited speakers, seven oral concurrent sessions and two poster sessions. Overall, 62 oral papers and 57 poster papers were presented in the conference. The LIL Management Office wishes to thank TMAC Chair, Julia Kornegay, for her tireless leadership of the TMAC and dedication in preparing the conference program.

The 2017 Grain Legume Conference was attended by approximately 150 Legume Innovation Lab scientists, sponsored graduate students including the five Legume Scholars, collaborating scientists, USAID representatives from Washington and regional Missions, and approximately 20 local INERA, university and Ministry of Agriculture cowpea scientists in Burkina Faso. The MO again made a special effort to support the participation of young grain legume scientists and LIL sponsored graduate students to that they would have an opportunity to present their research findings and to network with other scientists in diverse disciplines from Africa, Latina America and the U.S. working on grain legumes.

The Legume Innovation Lab MO continued to provide contractual, financial and administrative leadership of the "Legume Scholars Program." Although both ICRISAT and the PMIL at the University of Georgia established contracts with LIL to partner in financially supporting the LSP program and the training of the five PhD Legume Scholars (total budget of $1,500,000), an agreement was reached among the partners including USAID to charge all expenses through FY 17 to the ICRISAT account. MSU has established subcontracts with five U.S. universities where the five LS are enrolled in graduate programs (Kansas State University, Iowa State University, Michigan State University, University of California- Davis, and University of Georgia). See section XII of this FY 2017 report for additional details on the Legume Scholars Program.

On June 23, 2017, USAID issued a Cooperative Agreement associate award AID-OAA-LA-17-00002, "Legume Scholars Program" under AID-EDH-A-07-00005 for the performance period April 1, 2017 through September 30, 2019. MSU received an initial obligation of $500,000 from USAID of the Total Estimated USAID Amount (TEA) of $750,000. During the ensuing months, the MSU established subcontracts with the four universities (KSU, ISU, UCD and UGA) where the Legume Scholars students are enrolled in PhD programs. Cynthia Donovan (Deputy Director of LIL) is serving as the PI of the LSP associate award with Kade Sharrow providing support as program coordinator.

A priority of the LIL Management Office in FY 2017 was to complete all contractual technical and financial commitments to USAID and to make preparations for the LIL program close down on 30 November 2017. The following activities were carried out in FY 2017.

a. Technical Reporting

The Management Office obtained the following technical reports from all subcontracted research and capacity building projects.

- FY 2017 Feed the Future Performance Indicators data
- FY 2017 LIL Project Annual Technical Progress Report (includes a report of both short term and degree training)
- Final LIL Project Technical Report (FY 2007 – 2017)

With these project reports, the MO compiled the data and submitted performance indicator data and technical reports for the LIL program to USAID. The Final LIL Program Report (2007 – 2017) will be submitted to USAID prior to February 28, 2018.

b. Financial Management and Reporting

The Management Office provided financial oversight of subcontracted projects to ensure that funds were expended and invoiced in a timely manner in accord with approved workplans and budgets. Regular communications including conference calls were held with project PIs and institutional financial officers throughout 2017 to discuss the financial status of projects, project deliverables, cost share commitments, end of project financial and technical reporting and the disposition of equipment purchased during the program. Based on all feedback received, subcontracted projects are projected to expend all obligated funds for collaborative research and training activities.

The Management Office has also been monitoring closely its own expenditures for salaries, operational expenses, travel, TMAC and conferences. Financial records indicate that the MO has achieved economies and under spent relative to the budget in the Cost Application for the program.

c. Equipment Disposition

A form has been sent to Lead Project PIs requesting information on the status of "equipment" procured with USAID funding from either the DGP CRSP and LIL, plus recommendations regarding the future disposition/ownership of the equipment. The feedback received will be compiled and submitted to USAID for resolution of equipment disposition.

d. Cost Share Commitments

The Management Office obtained written Cost Share commitment reports from all subcontracted U.S. universities including from Michigan State University. Since Cost Share was required in the LIL Program, the amount of cost share to be provided by each institution was identified in each project subcontract. Based on cost share reports received to date, Michigan State University believes that it will be able to fulfill its cumulative Cost Share commitment for the period FY 2007 to 2017.

The MO compiled in 2017 a full bibliography of scholarly publications and presentations produced by PIs and collaborating scientists involved in the Dry Grain Pulses CRSP and the Legume Innovation Lab (FY 2007 – FY 2017) to give evidence of substantial scientific achievements and technical outputs by the program.

Michigan State University has provided university funding to temporarily retain several LIL Management Office staff for up to three months (until February 28, 2018 at the latest) to complete all administrative tasks associated with fulfillment of all of its Management Entity contractual commitments relative to the Feed the Future Legume Innovation lab with USAID.

Issues

The transaction costs for Management Entities (U.S. universities) to administer Innovation Lab programs continue to increase with the addition of new and changes in USAID standard provisions (i.e., EMMP, Open Data, Participant Training, International Travel Authorization, etc.) and the constant receipt of requests for both technical and financial (i.e., pipeline, accruals) information from USAID's BFS staff. As a consequence, MO staff need to dedicate an increasing amount of effort to administrative tasks so as to ensure compliance rather than focusing on providing technical leadership and monitoring of project performance. In addition, it has necessitated that MOs increase their staff to be positioned to effectively administer the IL programs and to respond to USAID requests in a timely manner. These issues will likely be major challenges for future Innovation Labs which have less experience in managing USAID programs or for universities which are less internationally engaged.

Future Directions

- MASFRIJOL project activities in Guatemala will continue to be implemented through March 31, 2017 in accord with the workplan and budget approved by the USAID Mission to Guatemala. The contract for the MASFRIJOL Associate Award is projected to end in March 2018 unless extended. Due to the excellent performance of the project and outstanding evaluations by partners, the USAID Mission to Guatemala has expressed an interest a one-year funded extension that focuses on increasing the scope and sustainability of the "Almacenes Comunitarios de Semilla" (community seed depots) and the nutrition education effort. These are areas with the MO believes will have major impact to both food and nutritional security of rural Mayan communities in the Western Highlands of Guatemala, and which are synergistic to the other FTF activities of USAID in Guatemala.

- Dr. Widders will retire as Director of the Legume Innovation Lab effective February 28, 2018. Dr. Donovan will remain at MSU engaged in current and future activities related to her professional interests, including training efforts, technology development and adoption, and seed systems.

- A limited number of staff will be retained on an interim basis by Michigan State University to manage the contractual and financial commitments for the Legume Scholars Program and MASFRIJOL associate awards. Salary support for these staff will be cost shared by Michigan State University and the projects.