FEED THE FUTURE

The U.S. Government's Global Hunger & Food Security Initiative

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes

Technical Highlights 2015

USAID FROM THE AMERICAN PEOPLE

Legume Innovation Lab

The cover photo depicts the measurement of a child's arm circumference in Malawi, in connection with the SO3.1 project *Legumes, Environmental Enteropathy, the Microbiome, and Child Growth in Malawi*. Arm measurement is an uncomplicated technique that can be done with simple measuring tape and can replace the need to measure body weight and length. Small arm circumference indicates moderate or severe malnutrition and immediately alerts the measurer that feeding is necessary.

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

FY 2015 Technical Highlights

October 1, 2014–September 30, 2015

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Table of Contents

Abbreviations and Acronyms

ADP ....Andean Diversity Panel
ALS.............Angular Leaf Spot
AOR ....Agreement Officer's Representative, USAID
ARS ....Agricultural Research Service (USDA)
ATA ....Agricultural Transformation Agency
BCMV ....Bean Common Mosaic Virus
BCMNV ......Bean Common Mosaic Necrosis Virus
BGYMV.......Bean Golden Yellow Mosaic Virus
BHEARD.....Borlaug Higher Education Agricultural Research and Development Program
BIC ....Bean Improvement Cooperative
BNF ....Biological Nitrogen Fixation
Bt................*Bacillus thuringiensis*
BTD ....Bean Technology Dissemination
CBB ....Common Bacterial Blight
CEDO ....Community Enterprises Development Organisation
CGIAR ....Consultative Group on International Agricultural Research
CIAT............Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
CRI ....Crops Research Institute (Kumasi, Ghana)
CRSP..........Collaborative Research Support Program
CSB ....Community Seed Bank
CSIR ....Council for Scientific and Industrial Research (Ghana)
DARS..........Department of Agricultural Research Services
DCO............District Commercial Officers
DEPI............Dynamic Environmental Phenotyping Imagery
EAP.............Escuela Agrícola Panamericana–Zamorano (Honduras)
FMS ....Farmer Management System
FTF ....Feed the Future
GWAS ....Genome-Wide Association Study
HC ....Host Country
HIS..............High Input System
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)
IDIAF...........Instituto Dominicano de Investigaciones Agropecuarias y Forestales
IFS ....Improved Farmer System
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)
INIAP ....Instituto Nacional Autónomo de Investigaciones Agropecuarios (Ecuador)
INRAN ....Institut National de la Recherche Agronomique du Niger (Niger)
INTA............Instituto Nacional de Tecnologías Agrícolas (Nicaragua)
IPs ....Innovation Platforms
IPM-omics..Integrated Pest Management-omics
ISRA ....Institut Sénégalais de Recherches Agricoles (Senegal)
KSU ....Kansas State University
LUANAR .....Lilongwe University of Agriculture and Natural Resources
MAS............Marker-Assisted Selection
MDP ....Middle American Diversity Panel
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 Publica 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)
PCCMCA....Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales
PHI..............Pod Harvest Index
PI ....Principal Investigator
QTL.............Quantitative trait loci
RCBD ....Randomized Complete Block Design
RESOPP .....Le Réseau des Organisations Paysannes et Pastorales du Sénégal/Network of Farmer and Livestock Organizations of Senegal
RFP.............Request for Proposals
RIL ....Recombinant Inbred Lines
SABREN .....Southern African Bean Research Network
SARBEN .....Southern African Regional Bean Evaluation Nursery
SARI ....Savannah Agriculture Research Institute (Tamale, Ghana)
SAWBO ......Scientific Animations Without Borders
SCAR..........Sequence Characterized Amplified Regions
SNF ....Symbiotic Nitrogen Fixation
SNP ....Single Nucleotide Polymorphism
SO ....Strategic Objective
SUA ....Sokoine University of Agriculture Tanzania)
TAT..............Tepary Adaptation Trials
TDP.............Tepary Diversity Panel
TMAC ....Technical Management Advisory Committee
UCR............University of California, Riverside
UNZA..........University of Zambia
UPR ....University of Puerto Rico
USDA..........United States Department of Agriculture
Vis/NIRS.....Visible and Near-Infrared Reflectance Spectroscopy
ZARI ....Zambian Agriculture Research Institute (Zambia)

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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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Michigan State University, USDA/ARS
Prosser, Washington, USDA/ARS
Tropical Agriculture Research Station, Mayaquez, Puerto Rico

Subcontracted International Institutions

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Burkina Faso	Institut de l'Environnement et de Recherches Agrícolas (INERA)
Ghana	Crops Research Institute (CRI)
	Savannah Agriculture 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) Consejos Comunitarios de Desarrollo (CECODE)
Haiti	National Seed Service (NSS), Ministry of Agriculture
Honduras	Escuela Agrícola Panamericana–Zamorano (EAP–Zamorano) and Dirección de Investigación y Tecnologías Agrícolas (DICTA)
Malawi	Lilongwe Univesity of Agriculture and Natural Resources (LUANAR)
Mozambique	Instituto de Investigação Agrária de Moçambique (IIAM)
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)

Preface

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

Throughout the world today, more than 800 million people suffer from chronic hunger, with more than 34 million children in developing countries suffering from acute malnutrition due, in large part, to the ongoing persistence of food insecurity. With chronic hunger and malnourishment rooted in the rural poverty of developing countries, the need for research scientists to develop sustainable strategies that address the agricultural challenges of smallholder farmers within affected countries lies at the heart of Feed the Future's mission to create a healthy, food secure, and well-nourished world.

Grain legumes represent a diverse group of edible leguminous crop species, including common bean, cowpea, lima beans, pigeon pea, tepary beans, lablab, and lentils that contribute significantly to household food and nutritional security while also improving soil health. Nutrient-dense and affordable, grain legumes are considered a staple food throughout the world as well as a cash crop for resource-poor smallholder farmers, many of whom are women, in Africa and Latin America. For these reasons, grain legumes are a research priority crop for Feed the Future in harnessing scientific innovation and technology in agriculture and nutrition; Feed the Future recognizes that advancing science research is key to reaching its core objectives of reducing global hunger, poverty, and undernutrition.

In keeping with these priorities, USAID's Office of Agriculture, Research and Policy, Bureau of Food Security awarded a $24.5 million, 4.5 year extension (April 1, 2013, through September 30, 2017) of the Legume Innovation Lab program, previously branded the *Dry Grain Pulses Collaborative Research Support Program (Pulse CRSP)*. In alignment with Feed the Future, the Legume Innovation Lab's technical approach is built on the premise that science, technology, innovation, and collaborative partnerships can accelerate the achievement of development outcomes more quickly, more cheaply, and more sustainably. This extension confirmed USAID's recognition of the importance of grain legumes for cropping system sustainability and the enhancement of dietary quality as well as the value of its collaborative research strategy. The Legume Innovation Lab draws on top U.S. universities and developing country research institutions to access cutting-edge research capacities and expertise to address challenges and opportunities facing the grain legume sectors in Feed the Future focus countries through a program that has spanned more than 30 years.

In keeping with Feed the Future's research strategy, Legume Innovation Lab projects focus on four strategic objectives that build on earlier program achievements. The global program goal of the Legume Innovation Lab is to substantively increase grain legume productivity through sustainable intensification of smallholder farm systems to increase the availability of affordable grain in domestic markets, increase consumption of legumes by the poor, and improve nutrition and nutritional security of critical populations in developing countries. This overarching goal is broken down into four Strategic Objectives (SOs).

Strategic Objective 1: Advancing the Productivity Frontier for Grain Legumes

- To enhance the genetic yield potential of grain legumes by improving resistances to economically important abiotic and biotic constraints that limit yield.
- To sustainably reduce the yield gap for selected grain legume crops produced by smallholder, resource-poor farmers in strategic cropping systems.

Strategic Objective 2: Transforming Grain Legume Systems and Value Chains

- To transform grain legume-based cropping systems through improved soil fertility operations and better management of value chains.

Strategic Objective 3: Enhancing Nutrition

- To improve the nutritional quality of diets and enhance the nutritional and health status of the poor, especially young children and women, through increased consumption of beans and cowpeas.

Strategic Objective 4: Improving Outcomes of Research and Capacity Building

- To assess the impacts of investments in research, technology dissemination, and institutional capacity strengthening to improve program effectiveness.

The 10 projects presented in the *FY 2015 Technical Highlights Report* involve collaborative research, long- and short-term training, and technology dissemination activities in 10 Sub-Saharan African countries (Benin, Burkina Faso, Ghana, Malawi, Mozambique, Niger, Senegal, Tanzania, Uganda, and Zambia) and three Latin American countries (Guatemala, Haiti, and Honduras). This report includes two projects not covered in the previous Highlights Report—*Legumes, Environmental Enteropathy, the Microbiome, and Child Growth in Malawi* and *Improving Photosynthesis in Grain Legumes with New Plant Phenotyping Technologies*, under SO1 and SO3, respectively.

This report highlights the technical progress and achievements made by Legume Innovation Lab projects during FY 2015, just a one-year snapshot; achievement of research objectives requires years of investment; even small advances within a research project represent a significant commitment of effort. Additionally, these highlights are condensed versions of more comprehensive technical reports that subcontracted U.S. universities provide annually to the Management Entity and USAID.

Technical progress reports are valued and utilized for assessing Legume Innovation Lab program performance and reporting by USAID to the U.S. Congress on Title XII and Feed the Future achievements and impacts. A small selection of noteworthy achievements for this fiscal year follows.

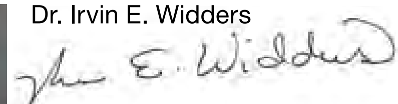
- DNA was extracted from 600 accessions of climbing beans from Guatemala and processed for SNP genotyping to assess genetic diversity.
- The Dynamic Environmental Phenotyping Imager (DEPI), the PhotosynQ platforms, the field deployable network of handheld sensors (MultiSpecQ), and the associated online communication and data analysis tools developed in the Kramer lab at MSU were validated for use in phenotyping of grain legumes in controlled and field environments. Initial results suggest that PhotosynQ in conjunction with MultiSpecQ measurements will be useful in providing early estimates of yield and the onset of diseases.
- The small light-red cultivar Paraisito Mejorado 2 (PM2-Don Rey), which carries BGYMV and BCMV disease resistance and possesses excellent adaptation to low soil fertility, was released for commercial production in Honduras.
- The effects of N, P, K, Mg, Ca, S, micronutrients and lime fertilization on common bean growth and development were elucidated from nutrient emission studies guided by analyses of chemical and physical properties of black, red, and stony soil samples from key production districts in Uganda and Mozambique.
- Formal release of five large white-seeded CRSP cowpea varieties (*Lisard*, *Thieye*, *Leona*, *Kelle*, and *Sam*) was completed in Senegal following the final performance testing in on-farm trials. Foundation seed of each variety was then produced by ISRA and distributed to farmers' organizations for Certified Seed development.

I encourage you to read the *FY 2015 Technical Highlights Report* in its entirety. A comprehensive view of the scope of vital outputs generated by each project and the new knowledge, management practices, and technologies resulting from the research activities provide an excellent picture of how the Legume Innovation Lab uses collaborative science research to advance food and nutrition security in developing countries. It is these outputs that will benefit stakeholders of grain legume value chains—from producers to consumers in Sub-Saharan Africa, Latin America, and the United States.

For more detailed information on the Legume Innovation Lab, including its technical vision, annual workplans, technical progress reports, funding, and links to websites with additional information on grain legumes, please visit the program's web page at www.legumelab.msu.edu. We also have a Facebook page (Legume Innovation Lab) and twitter feed (Legume InnovationLab) that regularly publish legume-related research.

As the director of the Legume Innovation Lab, I want to thank USAID for its financial support of this worthy program. USAID's investment in the Legume Innovation Lab under the Feed the Future presidential initiative is making a difference worldwide through its research and institutional strengthening activities on grain legumes. As a complement to the work of other international research programs (e.g., CG Research Program on Grain Legumes), the Legume Innovation Lab is making tangible contributions to the nutritional health and food security of the rural and urban poor as well as to providing opportunities for resource-poor farmers and other value chain stakeholders to generate income and escape poverty. The host country and U.S. scientists and institutions partnering in this endeavor are to be thanked and commended for their commitment to scientific excellence, to generating new knowledge and technologies that bring the hope of a better tomorrow, and to training a new generation of scientists and professionals who will provide leadership to the agricultural development of many African and Latin American countries.

Dr. Irvin E. Widders



Director
Legume Innovation Lab
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Genetic Improvement of Middle-American Climbing Beans for Guatemala

(SO1.A1)

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Abstract of Research Achievements and Impacts

The *Genetic Improvement of Middle-American Climbing Beans for Guatemala* project continues to make progress in testing and releasing improved climbing bean varieties for Guatemala's highlands. Ten lines have been tested in more than 15 locations in farmers' fields to gather information on agronomic performance and growers' feedback. An additional year of testing is needed before final decisions on releasing improved varieties can be made.

Commercial field at Parramos showing the *Milpa* system with maize and red beans

Three lines are demonstrating the best combination of seed yield and reduced aggressiveness that allows high productivity with maize under the *milpa* system. On-farm testing of *Bolonillo Texel* continues to confirm adaptation and acceptability by growers. Phenotypic variation within this line has been noticed, and we are making efforts to ensure genetic purity of the line.

The 600 accessions of the climbing bean collection were received at NDSU and are undergoing DNA extraction. The baseline study with approximately 500 growers was successfully completed and tabulated and is undergoing statistical analysis. In addition, seed samples from most growers surveyed were obtained and are being increased at ICTA greenhouses, providing an opportunity to assess the current genetic diversity among growers and to compare it with the original climbing bean germplasm collected 30 years ago.

Two women began their M.S. training in plant breeding and genomics at NDSU, ensuring bean scientists for Guatemala in the next generation. Additionally, new collaborations have been established with project SO4-1, *Impact Assessment of Dry Grain Pulses CRSP Investments in Research, Institutional Capacity Building and Technology Dissemination for Improved Program Efforts*, and MASFRIJOL to augment the success of the breeding efforts of this project.

Project Problem Statement and Justification

With approximately 11 million inhabitants, Guatemala is mostly a rural country, with 60 percent of the population living on farms and 50 percent of the population 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, which significantly affects children. Chronic malnutrition is frequent among children under five years old in the western highlands, with 67 percent affected, marking Guatemala as the country with the highest malnutrition level in the western hemisphere. One of every three children aged six to 59 months in the western highlands shows some evidence of anemia. Approximately 18 percent of reproductive-age women exhibit anemia, with 29 percent prevalence among pregnant women and 23 percent among breastfeeding women.

Climbing bean field at ICTA-Chimaltenango station showing crosses (white tags), with the fuego (fire) volcano in the background

Beans are grown on 31 percent of the agricultural land, mostly in the low- to mid-altitude regions (0–1500 meters above sea level [masl]) in a monoculture system. Contrastingly, intercropping (*milpa*, locally) 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 able to withstand biotic and abiotic stresses. Fungal and bacterial diseases and pests are the main cause for yield reductions. In addition, production includes almost no fertilizer inputs or other chemicals.

Historically, climbing beans have received less attention worldwide, with fewer 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 agroecologies in Central America, but research for the highland bean production systems is still lacking.

> *Farmers' trials included the local varieties/landraces used by the farmer as the local check to make side-by-side comparisons for these growers.*

There is an existing collection kept by ICTA of approximately 600 accessions of climbing beans collected from all bean production regions in Guatemala, characterized morphologically, agronomically, and with a few molecular markers (six SSR primers). Initial results suggest that half of the collection consists 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.

Objectives

1. Development of germplasm with improved disease resistance and agronomic performance
2. Characterization of the genetic diversity of this unique set of germplasm
3. A better understanding of the current socioeconomic status and needs of bean production within the context of intercropping systems in the region

Technical Research Progress

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

1.1. Field testing of 10 selected lines (ICTA)

A total of 10 climbing bean breeding lines that are at advanced breeding stages were selected to be part of field trials:

1. Bolonillo Altense
2. Bolonillo Hunapu
3. Bolonillo Texel
4. Bolonillo Anita
5. Bolonillo Labor Ovalle
6. Bolonillo San Martin
7. Bolonillo ICTA Santa Lucia
8. Voluble GUATE 1120
9. Voluble GUATE 1026
10. Local check from the grower (differs among farms)

Most of these breeding lines are the product of initial crosses made five to six years ago and subsequent composite mass selection and testing made by Dr. Fernando Aldana at the ICTA–Quetzaltenango station. Any superior line or lines could be released as varieties in the near future while a breeding pipeline is established. The trials were planted around May and grown at the ICTA–Quetzaltenango station and at farmer's fields in 17 locations (table 1).

Localidad	**Departmento**
Paxtocá	Totonicapán
Chuisuc	Totonicapán
San Antonio Sija	Totonicapán
Xe Sena	Totonicapán
Patachaj	Totonicapán
Choqui Alto	Quetzaltenango
Olintepe Que	Quetzaltenango
San Juan Ostuncalco	Quetzaltenango
San Padre Sacatepequez	San Marcos
Chiantla	Huehuetenango
San Sebastian	Huehuetenango
Santa Polonia	Chimaltenango
Comalapa	Chimaltenango
Tecpan	Chimaltenango
El Tejar	Chimaltenango
Zaragoza	Chimaltenango
Labor Ovalle	Quetzaltenango

Table 1. List of climbing bean trials (location and department) made during the 2015 growing season in the Guatemalan highlands.

Most locations were tested under the common intercropping system. Depending on space and resources at each location, the 10 entry trials were planted using a Randomized Complete Block Design (RCBD) with two or three replications. Farmer's trials also included the local varieties/landraces used by the farmer as the local check to make side-by-side comparisons for these growers. Harvest of these field trials should be finished by early December 2015.

Pod damage caused by the Mexican pod weevil (Apion *godmanii*), one of the main problems affecting plant production in Guatemala's Highlands.

All this extensive testing is coordinated by the field validation unit at ICTA (Julio Franco, coordinator), which is the final step before official variety release under ICTA standards.


Julio Villatoro, from ICTA, evaluating black bean breeding lines from the breeding program for developing resistance to anthracnose and other diseases.

Across locations, Bolonillo San Martin produced the highest seed yield, followed by Bolonillo Hunapu and Bolonillo Altense. Unfortunately, these genotypes are extremely aggressive in their growth; consequently, significant damage to the maize, mostly due to lodging, usually results. For this reason, growers have stopped planting beans in association with maize; culturally, maize is the most important crop for them and they don't want it damaged. This problem is even accentuated above 1500 masl because direct planting (vs. relay) results in greater competition between maize and bean. Consequently, the best combination of high seed yield and minimum damage to maize is offered by Bolonillo Santa Lucia, Bolonillo Texel, GUATE 1026, and Bolonillo Labor Ovalle. In addition, Bolonillo Anita was the most stable genotype across locations. The main production problems during the last two years were the Mexican weevil and rust, anthracnose, Ascochyta, and angular leaf spot.

1.2. Breeding pipeline and genetic purification of selected material (ICTA/NDSU)

Phenotypic variation has been detected not only within accessions but also within the improved lines selected by Dr. Fernando Aldana at ICTA–Quetzaltenango since Dr. Aldana kept these lines as bulked lines over multiple generations and, accordingly, no individual plant selections were made during the breeding process. Consequently, individual plant selections were made within the breeding lines during the 2013 growing season and planted again as plant rows at ICTA–Quetzaltenango.

Forty-three individual plant selections within each of the 10 lines listed in objective 1.1 were made based on potential yield and quality, absence of disease symptoms, pod distribution, and color and other agronomic traits. These individual selections were sent to the ICTA–San Jeronimo station for winter increase, and each selection was planted in individual rows for further evaluation/selection. This setup allowed for detection of additional genetic heterogeneity within lines while still increasing seed. Since phenotypic heterogeneity was still detected, more individual plants and some bulked rows were selected and sent to ICTA–Quetzaltenango for evaluations during the 2015 growing season. A total of 130 individual plant selections were planted as rows; harvest of this material was almost complete at the time of this report's submission. A final round of phenotypic evaluation will be made during FY 2016 to ensure a homogeneous source of breeder seed to start the seed increase process.


A healthy pod from a climbing bean.

Additional studies were focused on evaluating population dynamics and densities of the Mexican bean weevil in the four most promising breeding lines listed in objective 1.1. Finally, several rust mobile nurseries were deployed in different growing areas to assess the race structure of the pathogen across the region. At least nine rust races could be identified based on the disease reaction observed in the differentials. Please refer to Appendix 2 to find specific details and results about these complementary studies.

1.3: Field evaluation of Bolonillo-TEXEL (ICTA)

One of the improved lines selected by Dr. Fernando Aldana at the advanced breeding stages, *Bolonillo-Texel*, was also tested on growers' fields. Side-by-side *milpa* on-farm strip trials of the local's farmer variety/landrace and Bolonillo-Texel were grown (using the same maize material and agronomic practices) in five to six of the locations mentioned in table 1 as on-farm strip trials. Based on preliminary data previously collected by Dr. Fernando Aldana, ICTA–Quetzaltenango, Bolonillo-Texel is one of the most promising breeding lines. Since these trials are mostly managed by growers, data collection focuses mostly on seed yield, agronomic performance, and personal feedback from each grower. Technical assistance from ICTA agronomists and crop extension personnel from the Ministry of Agriculture have been crucial for finding growers and locations.

Differences in pod color were noticed in these trials, confirming the genetic heterogeneity still present in Bolonillo Texel, which is a concern for this breeding project; we are following all the activities necessary to obtain a uniform variety at the end of this project.

1.4. First crossing block

Using results obtained from field testing and the evaluation of germplasm collected during the 2014 growing season, a first set of 23 potential parents were selected and planted in the greenhouse at the ICTA station in Chimaltenango in 2015. Parental accessions were selected mainly based on uniform pod distribution, potential yield, and disease resistance. F1 seed is being harvested; complementary crosses will be initiated during the 2016 growing season to ensure a continuous breeding pipeline for the future.

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

2.1: Evaluation of core collection with the 6K SNP chip (NDSU)

This activity had to be postponed due to the poor condition of seed available from the germplasm collection stored at ICTA–Chimaltenango, which doesn't have an infrastructure adequate for long-term seed storage. To solve the issue of seed quality, the project leaders decided to obtain a new field increase of the entire germplasm collection at the ICTA–Chimaltenango station, with the resulting fresh seed shipped to NDSU for DNA analysis. Seed shipped to NDSU in August 2015 coincided with the arrival of the three new students who will work with these accessions, one of whom will focus on the molecular characterization of the collection for her M.S. degree research. Seed from each accession of the climbing bean collection is currently being processed for DNA extraction and SNP genotyping.

2.2: Field evaluation of the ICTA collection of climbing beans (ICTA–NDSU)

The entire collection of climbing beans from ICTA was planted in FY 2014 at the ICTA station in Chimaltenango to allow a re-evaluation of the material and the production of a newer batch of seed. A first set of 23 potential parents were selected and planted in the greenhouse at the ICTA station in Chimaltenango during the 2014 growing season for initial crosses. Parental accessions were selected mainly based on uniform pod distribution, potential yield, and disease resistance. Since the entire collection was planted again during FY 2015, it gave us an opportunity to re-evaluate the 23 accessions selected the year before. These selected accessions were used for the first set of crosses described in objective 1.4.

Close-up of a cross from the greenhouse at ICTA-Chimaltenango

Studies were focused on evaluating the population dynamics and densities of the Mexican bean weevil in the four most promising breeding lines.

Objective 3: A better understanding of the current socioeconomic status and needs of bean production within the context of intercropping systems in the region

A grower survey was deployed in March 2015 in the main regions climbing beans are produced. A group of approximately 15 surveyors was selected and trained by David DeYoung and Byron Reyes. Approximately 500 growers across five departments were surveyed during the three- to four-week period during March 2015. Focus was on the following departments, based on some stratified analysis: Quiche, Huehuetenango, San Marcos, Totonicapán, and Quetzaltenango, which represent most of the climbing bean production areas.

Various mottled beans grown in Guatemala

Collected data has been entered into a digital format (Excel) by ICTA personnel and is currently under revision and filtering of errors at MSU. During FY 2016, data will be analyzed and results summarized. Results of this survey will be shared not only within the project but with other projects currently working in Guatemala and interested government agencies. Initial results were shared at the *Joint Pan-African Grain Legume and World Cowpea Conference* in Zambia in March 2016.

Pod cluster from a climbing bean accession grown in the greenhouses at ICTA-Chimaltenango

An interesting activity performed during the survey was the request for a seed sample (~10 seeds) from each grower surveyed; approximately 85 percent of those surveyed agreed and gave us a sample of the seed they use on their farms. We now have a new set of 540 climbing bean germplasm accessions representing what growers currently use in their fields. Four seeds per sample were planted in the greenhouse for increase and future evaluation during FY 2016.

Future activities with this set of germplasm include comparing the original germplasm collection from ICTA with the new collection and determining which changes in genetic diversity can be detected. This comparison will provide an opportunity to conduct a phenotypic evaluation of the germplasm collected during the survey and, possibly, to identify genetic material of interest for the breeding pipeline. In addition, the specific location where each seed sample was obtained is available, making some geographical diversity analyses possible. Even more, the new germplasm collected during the survey could be compared with the original germplasm collection through SNP analysis to establish genetic similarities and possible geographical origin of the original germplasm collection, for which all passport data was lost.

Major Achievements

1. Establishment of a breeding pipeline and first set of crosses
2. Initial molecular characterization (DNA extraction) of climbing bean collection
3. Collection of seed samples from surveyed growers and seed increases in the greenhouses

Research Capacity Strengthening

The project successfully obtained one of the capacity strengthening awards for host countries. These funds were used to support activities related to the PCCMCA annual meetings (Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales), the most important scientific meeting in Central America and the Caribbean regarding crop and animal production research. The meeting, hosted by ICTA in Guatemala City, May 4–7, 2015, attracted approximately 300 participants from the region.

Human Resource and Institution Capacity Development

Short-Term Training

A three-day workshop to train surveyors on conducting the grower baseline survey was conducted at ICTA–Guatemala by Michigan State University and CIAT in ICTA Quetzaltenango, March 5–7, 2015. Guatemala benefitted from this training.

Scholarly Accomplishments

Osorno J.M. 2015. Avances en las secuencias genomicas de cultivos. Annual Meetings PCCMCA. Guatemala City, Guatemala. May 1–5. Oral presentation.

Tobar-Piñon M.G., Illescas O.V., and Villatoro J.C. 2015. Evaluación sensorial y de aceptación de productos alimenticios a partir de variedades de frijol (*Phaseolus vulgaris*) biofortificado. Annual Meetings PCCMCA. Guatemala City, Guatemala. May 1–5. Oral presentation.

Montejo, L.M., Villatoro, J.C., and Dardon, D. 2015. Identification of physiological races of common bean rust (*Uromyces appendiculatus*). Annual Meetings PCCMCA. Guatemala City, Guatemala. May 1–5. Poster presentation.

Maldonado-Mota C., Villatoro J.C., Miranda A., Moscoso-Alfaro J., Aldana L.F. 2015. Fitomejoramiento de frijoles (*Phaseolus vulgaris*) biofortificados para Guatemala. Annual Meetings PCCMCA. Guatemala City, Guatemala. May 1–5. Poster presentation.

Improving Photosynthesis in Grain Legumes with New Plant Phenotyping Technologies

(SO1.A2)

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Abstract of Research Achievements and Impacts

To avert food shortages and feed its growing population, Zambia, which ranks 164 out of 184 countries in the Human Poverty Index, needs to increase its productivity of grain legumes, which are important for both food protein and household income. Bean production, however, is constrained by its low inherent photosynthetic efficiency, which is highly sensitive to abiotic and biotic stresses, including diseases, pests, low soil fertility, heat, and drought.

To achieve major yield gains, the robustness and efficiency of photosynthesis must be improved, which requires the combined application of advanced genomics and high throughput phenotyping. A critical step in this direction requires 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. It also requires testing the new PhotosynQ research platform 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.

The approach is to harness two new phenotyping technologies, the *Dynamic Environmental Phenotyping Imager (DEPI)* and the *PhotosynQ platform*, a field-deployable network of handheld sensors *(MultispeQ)* and associated online communication and analysis tools.

Project Problem Statement and Justification

The goals of the research are to assess the possibilities of

1. accelerating breeding efforts to improve grain legumes using two innovative technologies for high resolution, high throughput phenotyping, and
2. integrating these tools into a region-led, multinational effort to improve grain legumes for agricultural production in Africa.

The project addresses several challenges that currently limit the application of these techniques for phenotype-driven plant screening, selection, and engineering for agriculture in Africa, including the cost of the instrumentation, the availability of networks to share and to analyze results, and computational tools to interpret phenotypic measurements usefully in terms of genetic variations in yield and robustness. Advances in Internet communications, rapid prototyping and manufacturing, basic and applied science (including genetics, genomics, biological spectroscopy, and data mining) are providing opportunities for professional and citizen scientists everywhere to leapfrog old technological impediments and take leading roles in improving local crops. Furthermore, a dramatic drop in price and increase in accuracy of sensors means that tools to measure soil, seed, and plant health do not have to be prohibitively expensive for anyone, anywhere.

David Kramer with the MultispeQ

Objectives

1. Probing photosynthetic responses in Recombinant Inbred Lines (RIL) and Genome-Wide Association Study (GWAS) Lines.
2. Increase the capacity, effectiveness, and sustainability of agriculture research institutions that 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.

Technical Research Progress

Objective 1. Probing photosynthetic responses in RIL and GWAS lines

This objective aimed to determine if DEPI could reveal phenotypic differences in cowpeas and common bean recombinant inbred lines and genome-wide association study lines that could potentially be mapped. In the 2015 work period, we tested identified conditions that result in substantial photosynthetic phenotypic differences between selected cowpea and common bean parent lines; because of changes in the start date, we focused mostly on cowpeas.

We found clear differences in photosynthesis responses to fluctuating light, daytime temperature, and nighttime temperature (Figure 1). All three effects are potentially important for plant productivity. It is becoming increasingly clear that responses to rapid fluctuations in environmental conditions, especially light, are critical for the efficiency and robustness of photosynthesis. Interestingly, we saw large phenotypic variations with lower rather than higher daytime temperatures; this phenoptype may be important for breeding plants that perform well in cooler climates. Finally, the effects of nighttime temperatures are very interesting—and perhaps most immediately applicable—given the known effects of high nighttime temperatures on flower viability and yield.

These results set us up for more detailed experiments, specifically to determine if we could identify QTLs that condition these responses. Consequently, in the 2015–2016 work year, we will focus on building rapid, high throughput methodology for mapping QTLs associated with these properties using the DEPI platform. The key question we will ask is, how can we reliably (with high statistical power) probe photosynthetic responses in RIL and GWAS lines?

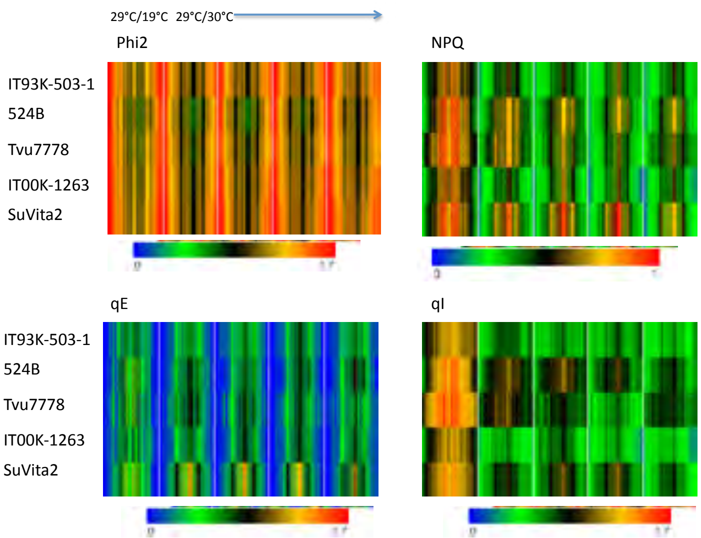


Figure 1. Differential effects of nighttime temperatures on photosynthetic parameters in five cowpea accessions. Shown are a series of heat maps taken over a five-day period depicting the responses of four photosynthetic parameters, the quantum efficiency of photosystem II (Phi2), nonphotochemical exciton quenching (NPQ), energy dependent NPQ (qE), and long-term or photoinhibitory NPQ (qI). On the first day, plants were exposed to 29°C during the day and 19°C during the night. On the second day, this regime was changed, so that the nighttime temperature was increased to 31°C.

Objective 2. Increase the capacity, effectiveness, and sustainability of agriculture research institutions that 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.

A major goal of this aim is to test the feasibility of using PhotosynQ to enhance local efforts to improve grain legume productivity. To achieve this, the project integrated our HC collaborators at each stage, enabled them to train and lead collaborators in both the United States and HC sites, and tested the utility of the platform in the host country.

In 2015, two graduate students—Isaac Dramadri (from Uganda, then in the Kelly lab at MSU), and Kelvin Kamfwa (from Zambia, then in the Kelly lab at MSU)—were trained in the operation, theory, and use of the PhotosynQ platform for local field application. They then used these devices to perform field experiments, the results of which are now being processed. We have also improved the reliability, calibration, and appropriate methodologies for the field experiments in greenhouses and fields at MSU.

A second advance in this objective was the validation and testing of the PhotosynQ platform. Isaac Osei-Bonsu performed key experiments that established that the PhotosynQ MultispeQ device was able to rapidly measure photosynthetic responses that are relevant to field conditions. He also showed that the two platforms (DEPI and PhotosynQ) produce comparable results, proving the ability to probe photosynthesis under both controlled laboratory and field conditions.

Taking meaurements using the MultispeQ and a mobile phone.

Using the MultispeQ to test for phenotypes on a common bean plant in Zambia

Additionally, we have initiated an analysis of data from both LIL-funded and other projects using PhotosynQ in an effort to determine which parameters and approaches may be useful indicators of the productivity and robustness of photosynthesis.

By comparing the results from multiple MultispeQ field trials in both Africa and the United States, we were able to develop methods that give early estimates of crop yield and the onset of diseases, which we think can be applied in Africa to crop management, determining the genetic bases of performance phenotypes, and directing breeding efforts.

It is important to note that the commonly used phenotyping measurements (SPAD, photosystem II photochemical efficiency) by themselves were poor predictors of yield or disease. However, MultispeQ provides rapid measurements of multiple (both traditional and novel) phenotypic parameters and multivariant analysis algorithms, including contributions from environmental and plant multiple phenotyping parameters, showed strong correlations with eventual yield. An example data set depicting the correlation models for seed yield for a trial using four sunflower varieties is shown in figure 3. MultispeQ data were taken during flowering. The standard photosynthetic parameter Phi2 (R2=0.15, top panel) showed only weak correlations, whereas an algorithm using five

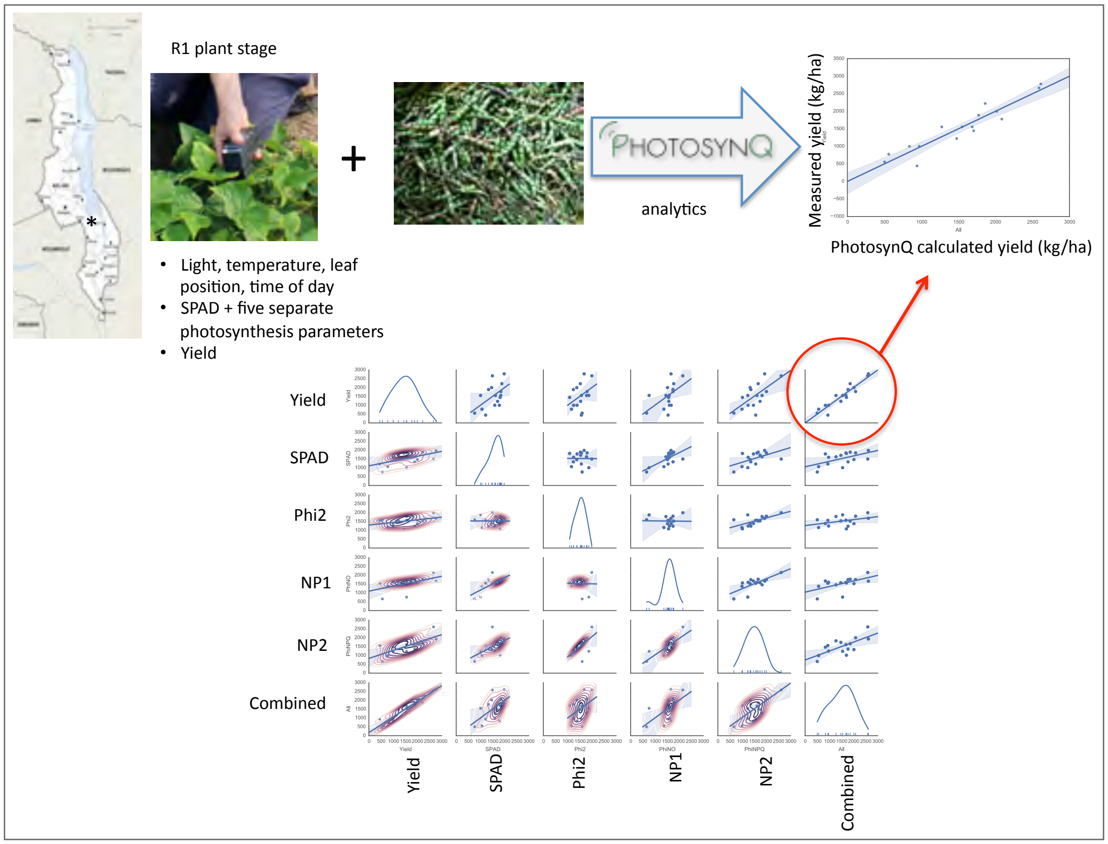


Figure 3. Early indicators of pigeonpea yield derived from MultispeQ field measurements and aggregate analysis on the PhotosynQ platform.

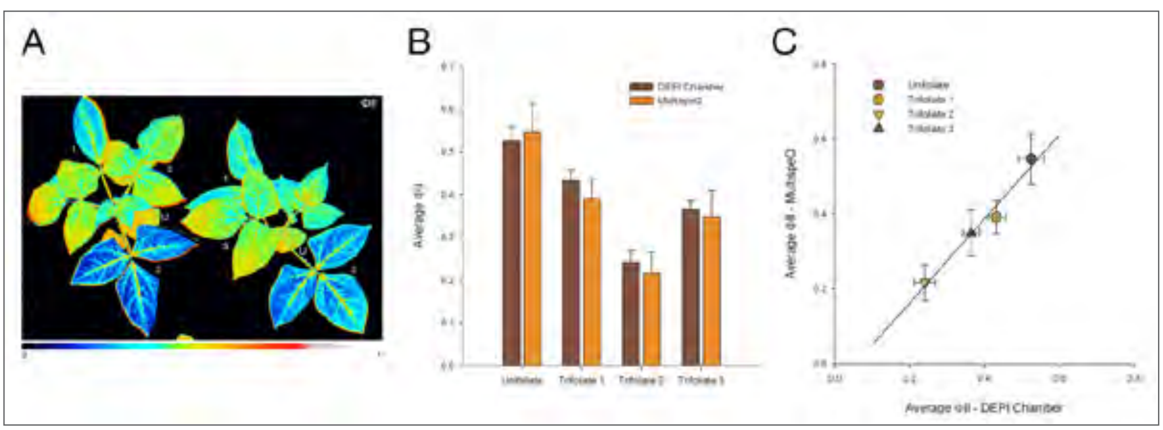


Figure 2. Comparing PSII yield (ΦII) measurements performed on cowpeas in a DEPI Chamber and using the MultispeQ, measuring the light intensity in the chamber and replicating it inside the MultispeQ using the red actinic LED. The measurements using the MultispeQ were taken on the same leaf used to determine ΦII from the image collected in the DEPI Chamber. (A) Example false color image of cowpea recorded in a DEPI chamber. The coloration represents the measured ΦII values as indicated in the color gradient below. U – Unifoliate, 1-3 – Trifoliate. (B) Averaged ΦII values from three biological replicates for the Unifoliate and the first three Trifoliates, comparing the DEPI Chamber and the MultispeQ. (C) Individual ΦII measurements recorded with both instruments. The line represents the linear fit (R^{2}= 0.9614).

parameters showed good correlation (R2=0.66, middle panel). When variety was included in the model, the correlation was further improved (R2=0.88, bottom panel). This result is important because it indicates the possibility of distinguishing between variety and field conditions' impacts on yield. Qualitatively similar results were obtained for pigeon pea (Malawi) and wheat (MSU).

In addition, trials on Soybean sudden death syndrome (Michigan) suggest that PhotosynQ parameters may be used as early indicators of disease.

Based on these results, we will accelerate and expand our proposed work.

Major Achievements

1. First proofs of concept for QTL mapping of photosynthetic properties in cowpea and common bean in controlled simulated environments
2. Validation of DEPI and PhotosynQ platforms

Research Capacity Strengthening

LIL support was used to test and validate the beta prototypes of the PhotosynQ and MultispeQ devices. Important lessons were gained about the manufacturing and calibration process, which were incorporated in the improved locked-beta units that were distributed in Africa. This knowledge was contributed to the new version of the instrument, which will be used to produce the next version of the MultispeQ due out in April 2016.


Exploring data through the PhotoSynQ application

A total of 10 beta devices, together with computer and other support, were produced for delivery to Zambia for the 2016 growing season and received by Dr. Kelvin Kamfwa early that year.

Several LIL participants have been trained in the use of the PhotosynQ platform, including co-PI Kelvin Kamfwa, graduate students DongHee Hoh, Isaac Osei-Bonsu and Jesse Traub, and collaborators Tom Close, U.C. Riverside; Phil Roberts, U.C. Riverside; and Phil McLean, NDSU.

PhotosynQ Lending Library

We established a PhotosynQ Lending Library program, allowing partners access to instruments and training, which consequently required relatively few devices for collecting large amounts of data. This library has created a large number of new users in Africa. There are clear differences in photosynthesis responses to fluctuating light, daytime temperature, and nighttime temperature compared to the United States. The library has also served our LIL collaborators in California and North Dakota.

PhotosynQ Mobile Phenotyping Groups

Based on our experiences in several countries, we developed and implemented a platform for crews of qualified, trained data collectors to travel to experimental stations and farms to collect large amounts of high quality data over short time periods. This effort has been very successful, increasing the number of projects, the number of data points taken, and the quality of the results. As a result of this success, we have replicated this program at several locations, including in the United States.


A trained phenotyping crew in Zambia

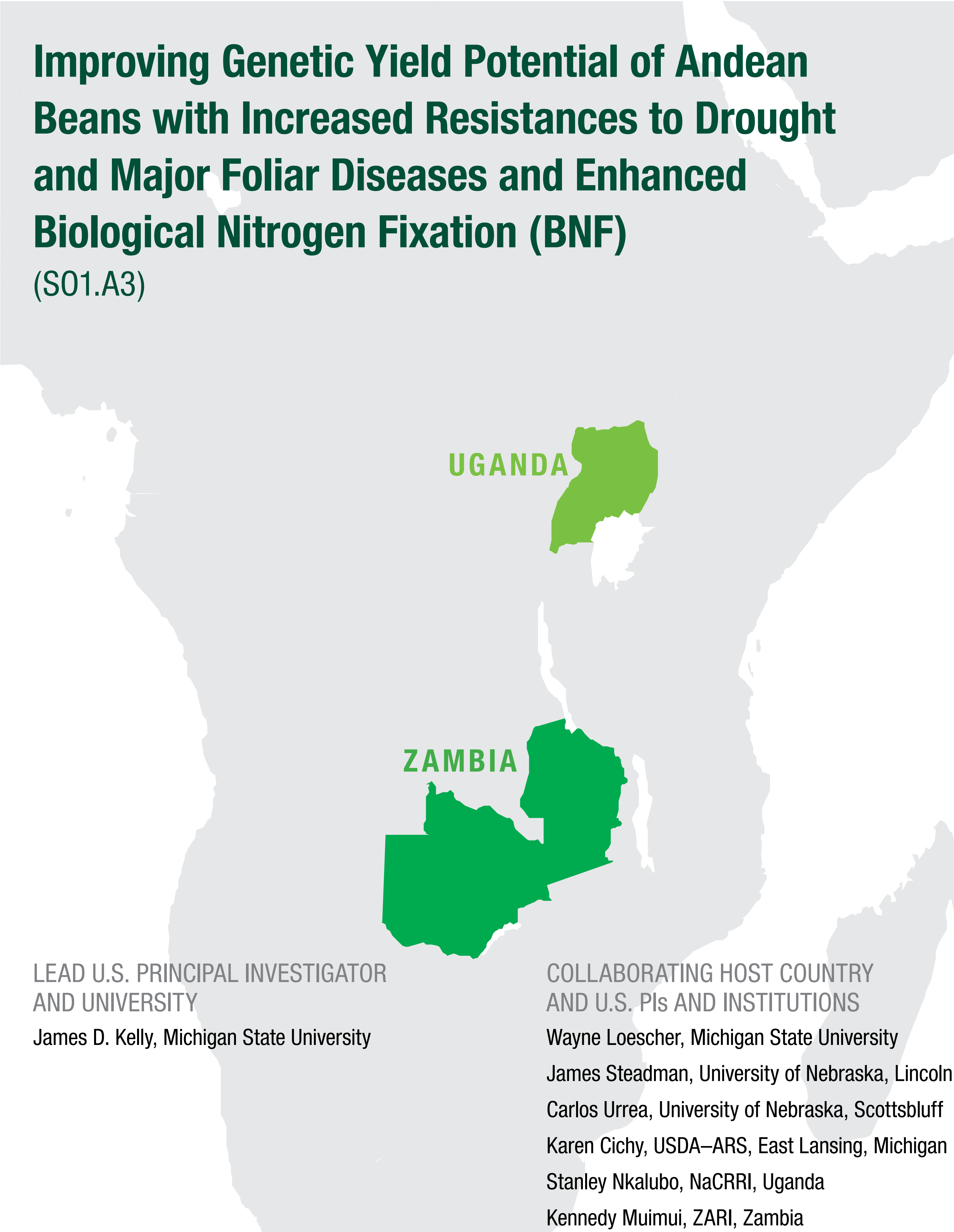
Human Resource and Institutional Capacity Development

Short-Term Training

Training on how to use the PhotosynQ platform was conducted through Michigan State University, the University of Zambia, and online for numerous graduate students and LIL PIs from four other LIL-sponsored projects. Uganda, the United States, and Zambia benefitted from this training.

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

(SO1.A3)



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Abstract of Research Achievements and Impacts

Common bean is the most important grain legume consumed in Uganda and Zambia. The development of improved bean varieties and germplasm with high yield potential, healthy root systems, improved symbiotic nitrogen fixation (SNF) with resistance to multiple diseases, and sustained or improved water use efficiency under limited soil water conditions is needed to increase profit margins and lower production costs.

An improved understanding of plant traits and genotypes with resistance to multiple stresses from abiotic (drought) and biotic (root and foliar pathogens) sources will provide unique genetic materials for enhanced plant breeding methods and sources to study plant tolerance mechanisms in common bean. Improvements in current understanding of the physiology of drought and evapotranspiration and the genetics of drought tolerance in common bean and the development of effective molecular and quantitative methods for the selection of drought tolerance are needed.

The project will use QTL analysis and SNP-based genome-wide association mapping to uncover regions associated with drought tolerance, anthracnose resistance, enhanced SNF, and shorter cooking time.

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. Sixty-two percent of the bean crop is produced on 60,000 ha in the higher altitude, cooler and high rainfall zones of the northern part of Zambia. Andean beans are predominant and landraces are the most widely grown, although a few improved cultivars are also grown as sole crops or in association 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, reflected in very low national yields, ranging from 300 to 500 kg/ha that result in an annual deficit of 5,000 MT.

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, since Zambia ranks 164 out of 184 countries in the Human Poverty Index.

Beans are an important crop in Uganda and are grown on more than 660,000 ha of land and consumed throughout the country. Beans are a major source of food and income for rural smallholder farmers, especially women and children. The majority of bean production in Uganda relies on planting inferior landrace varieties that are generally low yielding due to their susceptibility to the major biotic and abiotic 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 percent 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 is needed to increase profit margins and 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 SNF, and faster cooking time.

Objectives

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 United States.
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, anthracnose, common bacterial blight, bean common mosaic virus, and bean rust present in Andean germplasm.

3. Use single nucleotide polymorphism-based genome-wide association mapping to uncover regions associated with drought tolerance, disease resistance, cooking time, and BNF to identify QTLs for use in marker-assisted selection to improve Andean germplasm.
4. Develop phenometric approaches to improve the efficiencies of breeding for abiotic stress tolerance, especially drought.

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 United States.

1.1. Evaluation of integrated nursery in Uganda

During this year, several nurseries (some listed below) have been evaluated; from these nurseries several lines have been selected as sources of resistance or for conducting yield trials and/or genetic studies. A series of segregating populations and nurseries bred for drought tolerance have been received and together with lines generated within the country have been evaluated in the Ugandan environment including:

Thirty-five PIC drought tolerant large-seeded breeding populations were obtained from South Africa (ARC–Grain Crops Institute-Potchefstroom) from which 421 individual plants have been selected based on adaptation, plant architecture, number of pods, seed size, seed color, and yield as well as attributes suitable for the Uganda market. These plants have been planted to establish families that will be further screened for drought and other biotic stresses.

Adaptation and preliminary yield trials were conducted on-station at NaCRRI, Namulonge, for a total of 169 newly acquired drought bean lines obtained from CIAT. From these, 98 lines that showed promise (i.e., yielded greater than 1,500 kg/ha) were selected for further evaluation and utilization in Uganda's drought breeding program.

Evaluation of ADP (Andean Diversity Panel) lines is being undertaken on two fronts; in the first evaluation, a panel consisted of 250 genotypes, of which 233 were from the global ADP panel and 17 local genotypes were evaluated for drought at end of the first season (May–August 2014) on-station at NaCRRI–Namulonge, targeting off-season planting.

The field (second) experiment consisted of two treatments (irrigated and nonirrigated), in two replications planted in the field and the use of PhotosynQ for measuring photosynthetic traits in common bean under field conditions. Unusually high rainfall resulted in no drought stress being observed; however, the moist conditions led to multiple disease conditions and data were collected on all agronomic traits and on major common bean diseases (ALS, rust, CBB, and BMCV), which were observed on more than 80 percent of the ADP lines, with ALS and rust the major diseases challenging these lines.

In the other experiment, 23 ADP lines with faster cooking time with one local check are being evaluated on-farm in a participatory variety section using the mother-baby trial evaluation method. The trials are directly engaging 326 farmers, of which 230 are women, within nine famer groups. This experiment is currently at R7. At the end we hope to identify at least one fast cooking line possessing characteristics preferred by Ugandan famers.

Anthracnose and Pythium root rot. Use is being made of 43 breeding populations that had been pyramided with three anthracnose and one root rot (Pythium) genes and are being advanced and evaluated in field condition on-station; 144 individual plants were selected from the 43 breeders. The selected lines have been established in yield trials to evaluate performance and advance promising families.

1.2 Evaluation of Integrated Nursery in Zambia

A regional nursery, Southern Africa Bean Evaluation Nursery consisting of 100 genotypes of various market classes and traits was evaluated at Misamfu Research Station in Zambia for major diseases and yield. The highest yielding genotype gave 3,046 kg/ha. Among these diseases, CBB had high incidence compared to ALS, ANT, Rust, and BCMV. Most lines were found to be resistant/tolerant to ANT, BCMV, and Rust. A number of lines were found to have combined resistance to most diseases that prevailed in the season.

. . . 23 ADP lines with faster cooking time . . . are being evaluated on-farm in a participatory variety section using the mother-baby trial evaluation method.

1.3 Identification of resistance sources in Uganda

A series of efforts have been initiated to identify resistance sources for different foliar diseases, most notably the screening of the acquired germplasm both in the field and in the screen house to establish the reaction of the different germplasm to different pathogens.

Rust resistance. To identify rust resistant lines, a germplasm collection of 143 lines of 30 landraces, 20 released and 93 introduced lines, including the 12 rust differentials, was screened. The introduced lines had been linked to drought tolerance, anthracnose, and possible rust resistance genes. Phenotypic and genetic characterization identified lines including Mexico 309, CNC, P1181996, Mexico 235, Redland Pioneer, Oura Negro, and Aurora. These lines have been utilized to introgress rust resistance into Ugandan germplasm.

Anthracnose and Angular leaf spot. We still rely on the differential genotypes like AB 136 and G2333 for anthracnose and Mexico 54 for ALS.

Common Bacterial Blight (CBB) resistance. To identify resistance sources to CBB, 132 genotypes of 80 local and 32 imported germplasm (from Nebraska) have been screened using the most prevalent *Xanthomonas campestris* pv. *phaseoli* (Xcp) isolate *Kawempe 1* in Uganda. We have so far identified six genotypes as the most resistant, all from the Nebraska CBB nursery.

Nebraska. The ADP was screened to common bacterial blight at the West Central Research and Extension Center in Nebraska in an augmented replicated trial. At flowering, plants were sprayed with a bacterial solution. The lines were evaluated at the pod filling stage using a 1-9 scale, where 1 = immune and 9 = very susceptible. In July 2015 a CBB Nursery of 50 entries selected from this CBB screening in Nebraska was sent to Uganda and Zambia for testing at both locations.

Drought tolerance. We obtained more than 150 drought tolerant lines that have been screened for adaptation in Uganda; some have been utilized in crosses. We intend to screen these in the field. No new drought tolerant lines have been identified as yet but five old CIAT lines have been utilized in making crosses and the progenies are being evaluated for consumer preferred agronomic traits and yield.

A drought evaluation nursery of 60 lines was planted during the off-season under irrigation for evaluation for drought in Zambia. A number of lines showed some tolerance. The nursery was harvested in November 2015.

The ADP lines were evaluated to terminal drought (irrigation was stopped at flowering) in Nebraska. Yield and 100-seed weight was reduced by 41.2 and 9.6 percent when beans were stressed, respectively. In July 2015, a 60-entry drought trial was assembled from these tested lines and dispatched to Uganda and Zambia for testing at both locations under normal and drought conditions.

Field Evaluation of the Nutritionally Superior Common Bean Genotypes with Farmers in Three Agroecological Zones in Uganda

Iron and zinc deficiency are the most prevalent micronutrient deficiencies in the world; common bean is an important source of micronutrients. Biofortification has the potential to address micronutrient malnutrition, especially in developing countries where plant-based staples are widely grown and consumed. The efficacy of biofortified crops to address human malnutrition can further be improved if genotypes with highly bioavailable minerals are developed.

Andean bean genotypes with high iron and zinc concentration and high iron bioavailability were identified from a set of diverse Andean bean germplasm using an *in vitro* caco-2 cell line assay. A subset of 23 of the best lines for mineral nutrition and also fast cooking are being evaluated in farmers' fields along with local check genotypes in a participatory variety selection in Hoima, Kamuli, and Masaka. Nine farmer groups of 40 farmers are participating in the research. There are three farmer groups per district and each group has a large garden planted with 23 experimental entries (genotypes) and one local check, so the mother trial has 24 entries as two field reps under RCBD. The farmers are from three districts representing three agroecological zones in Uganda that are important in both bean production and consumption. The study will help us identify which of the nutritionally superior genotypes might be well adapted for Ugandan conditions and are preferable to Ugandan farmers and consumers in addition to the breeding needs for nutritionally superior, fast cooking cultivars

1.1 Crossing and backcrossing resistance sources in Uganda
The project has embarked on the process of introgressing the different resistance genes into the backgrounds of some of the most preferred Andean bean varieties in Uganda.

Rust. Using the seven identified rust resistant sources, crosses have already been initiated with Ugandan market class bean lines to introgress rust resistance into their background.

Drought. To introgress drought tolerance into farmer and market bean cultivars, use was made of already known drought tolerant sources. Evaluations and selections are being made from the advancing of the progenies arising from 15 crosses that were made between Ugandan market class varieties and introduced drought tolerant varieties. Nine promising lines from nine different crosses have been selected and are currently undergoing preliminary yield trials on-station at NaCRRI.

Common Bacterial Blight. Cross have also been initiated between CBB resistant materials and four Ugandan Andean susceptible market class varieties to introgress CBB resistance.

> *Biofortification has the potential to address micronutrient malnutrition, especially in developing countries where plant-based staples are widely grown and consumed.*

Crossing and backcrossing resistant sources in Zambia. A number of lines from an early-generation trial of 60 selected lines from the F4s were constituted into a trial and evaluated at Misamfu, Zambia. The lines, which combined high yield with resistance to major diseases, performed very well. They are also large seeded, a Zambian preference. Forty-eight percent of the lines yielded above 1 t/ha. The lines are currently being advanced to F_5 under irrigation. Part of the seed of the selected lines will be tested for iron and zinc levels.

1.2 Evaluation of lines for SNF

Adaptation and evaluation trials for 68 low soil fertility and drought-tolerant genotypes obtained from CIAT–Colombia were conducted on-station at NaCRRI. The low soil fertility and drought tolerant materials were evaluated and multiplied to generate enough seed to test in other sites. These genotypes are currently being evaluated again for yield and other stresses.

1.3 Population development for genetic studies

We have started generating seed populations, especially for the new crosses that include populations for rust, CBB resistance, BCMV, and stem maggot resistance in hope that they will contribute to genetic studies for resistance to the different stresses in relation to the Andean Ugandan market class genotypes. Based on 2013 and 2014 data collected in Nebraska related to common bacterial blight, experiments on drought, and cooking time, 14 F1 combinations were initiated in 2015. A new set of hybrids is planned for December 2015.

1.4 Cooking time prediction in intact dry bean seeds using visible/near-infrared spectroscopy

Dry beans require long cooking times to become palatable and there is significant genetic variability for this trait. The objective of this study was to evaluate the utility of visible and near-infrared reflectance spectroscopy (Vis/NIRS, 400-2,498 nm) for predicting cooking time from intact dry seeds. A total of 475 bean samples of the ADP grown at the Montcalm Research Farm in Michigan, with wide variations in cooking time (15 to 90 min) were used in this study. Spectral preprocessing methods coupled with a feature selection method were tested for improving the prediction of cooking time using partial least squares regression models. Overall, the two-wavelength ratio preprocessing approach produced more precise results than smooth first and second derivatives or continuous wavelength transform. The Vis/NIRS technique appeared promising for predicting cooking time from intact dry seeds. The ADP panel was also grown under normal and drought stress in western Nebraska and the panel were cooked in a Mattson cooker. Seeds were soaked overnight (16 hours), then placed in the Mattson Bean Cooker, and cooked until 80 percent of the weighted plungers dropped. On average, the beans under normal conditions cooked at 59 minutes and beans under drought stress at 68 minutes.

1.5 Seed multiplication

A number of promising lines were increased to prepare for inclusion of the promising ones into trials for the 2015-16 cropping season in Zambia.

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, anthracnose, common bacterial blight, bean common mosaic virus, and bean rust present in Andean germplasm.

2.1 Anthracnose and Angular Leaf Spot characterization and screening in Uganda

We are collecting new diseased samples for these two pathogens.

2.2 Rust characterization and screening
We are currently collecting new samples for the identification of rust pathotypes in the field that we hope to characterize genotypically; we plan to determine race structure of new leaf samples.

Samples received in UNL from Zambia were leaves that were collected from the rust differential lines (mobile nursery) set out to monitor for rust near Kasama. No rust was collected from differential lines Mexico 309 (Ur-5) or PI 181996 (Ur-11). Based on the reactions of the differential cultivars in UNL greenhouses to the Zambian rust, the Ur genes -4, -6, -7, -12, -13, and -9 do not provide protection. However, cultivars with Ur-3, -3+, -5, and -11 would provide resistance.

2.3 Common Bacterial Blight screening
In Uganda already available pathotypes Kawempe 1 were obtained and utilized to screen the available CBB nursery for resistant sources and will be used it to screen for resistance in the resulting progenies. During screening, they inoculated the second trifoliate leaf of an 18-day-old plant using the razor blade method and two pods per plant during pod filling stage using the multiple needle scratch method.

2.4 Compile database of past pathogen collections in Uganda
Although still raw and rough, we have initiated a computer-based database. Collections made to date indicate areas of collection and numbers collected.

2.5 Anthracnose race characterization, screening in Zambia
Low pressure of ANT was observed during the season and from the nurseries that were evaluated at Misamfu. Screening for ANT was done using field infection. Due to dry spells that occurred during the season, screening for ANT was not up to date, although a number of lines were found to be resistant.

2.6 Angular Leaf Spot characterization, screening in Zambia
An ALS nursery consisting of 46 lines was evaluated at Misamfu. The lines were planted in an ALS hot spot so as to get a natural field infestation. The yield range was from 346 to 2,342 kg/ha. Line G9282 was the highest yielder and was found to be resistant to ALS, BCMV, and Rust but was intermediate or tolerant to CBB. Line BM 12732-57 VEF 2000 121 was resistant to all the diseases that were prevalent during the season but was small seeded, which is not liked by Zambian small-scale famers. This line could be used as source for resistance in the breeding program. High incidences of CBB were noticed during the season. ALS sources used in the region CAL 143 and AND 277 were still found resistant and were among the top yielders in this nursery, at 1,792 and 1,717 kg/ha, respectively.

2.7 Common Bacterial Blight Screening in Zambia
A regional common bacterial blight nursery of 49 lines were plated at Misamfu in single row plots. Most of the lines in the nursery had traceable parentage of VAX lines that are used in the region as CBB resistance sources. Data collected included days to flowering, stand at harvest, ALS, BCMV, anthracnose, CBB, rust, 100 seed weight, and yield. The mean yield for the nursery was 1,519 kg/ha from a range of 683 to 2288 kg/ha. Line BRB 265/VAX3-1 was found to be resistant to most diseases in the field but susceptible to rust. Line BRB 265/VAX3-8 was the only line with high CBB resistance.

2.8 Field ratings of rust and common bacterial blight in a root rot trial in Zambia
Data was gathered on rust and common bacterial blight severity on the foliage of 12 bean lines selected from earlier trials of 362 (2013) and 60 (2014) bean lines, including the Andean Diversity Panel and Nebraska select lines. The stem-maggot-insecticide-treated bean lines in some cases were less rust resistant than the untreated. Eight lines including three local landraces were resistant; four lines were moderately resistant, two lines were moderately susceptible, and one line was considered susceptible. The common bacterial blight reactions were very low with only two lines moderately resistant and the rest resistant. The best lines for resistance to both pathogens were Larga Commercial, PI 321094-D, NE 34-12-47, Local Mbbereshi, and Local Cim-Climb 03-48.

2.9 Mapping resistance genes for anthracnose
New sources of anthracnose resistance in a highly diverse panel of 226 Andean beans was screened with eight races of anthracnose to identify and map new sources of resistance using a Genome Wide Association Study (GWAS) at MSU. Only one line, *Uyole 98*, was resistant to all eight races. Outputs from the GWAS indicated major QTL for resistance on three linkage groups: Pv01, Pv02, and Pv04 and minor QTL on Pv10 and Pv11. Candidate genes associated with the significant SNPs were detected on all five chromosomes. A QTL study with the black bean cultivar *Jaguar*, known to possess resistance to anthracnose race 73, was conducted to determine the basis of the anthracnose resistance commonly used in the MSU

breeding program. Resistance to anthracnose was investigated in an F4:6 recombinant inbred line (RIL) population developed from a cross between Jaguar and Puebla 152 (landrace cultivar known to be susceptible to race 73). Resistance in Jaguar was determined to be conditioned by the single dominant gene *Co-1*. Using the Illumina BARCBean6K_3 BeadChip, the physical location of the *Co-1* locus was mapped between 50.3Mb on chromosome Pv01. A breeder friendly InDel marker was developed (50.2Mb) that was linked to the *Co-1* locus as 3.1cM and could be used in selecting four of the five resistance alleles at the Co-1 locus. The genomic positions of the numerous resistance loci on Pv01, Pv02, Pv04, and Pv11 identified in Jaguar and in the Andean panel should prove useful for breeding programs interested in improving anthracnose resistance in cultivars using marker assisted selection.

Objective 3. Use single nucleotide polymorphism-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.

To better understand the genetic architecture of SNF at the molecular level variability, three studies were conducted at MSU:

1. Genome-wide association study (GWAS)
2. Quantitative Trait Loci (QTL) mapping study
3. Transcriptome profiling study

GWAS was conducted using an ADP composed of 259 genotypes. The ADP was evaluated for SNF in both greenhouse and field experiments and genotyped using an Illumina BARCBean6K_3 BeadChip with 5,398 single nucleotide polymorphism (SNP) markers. A mixed linear model was used to identify marker–trait associations.

The QTL mapping study was conducted using 188 F4:5 recombinant inbred lines derived from a cross of Solwezi and AO-1012-29-3-3A. These 188 F4:5 RILs were evaluated for SNF in greenhouse experiments and genotyped using the same BeadChip. Transcriptome profiling was conducted on RILs SA36 and SA118 contrasting for SNF that were selected from the Solwezi x AO-1012-29-3-3A population used in the QTL mapping study. RNA samples were collected from leaves, nodules, and roots of SA36 and SA118 grown under N fixing and nonfixing conditions and sequenced using Illumina technology. Using GWAS, significant associations for nitrogen derived from atmosphere (Ndfa) were identified on specific chromosomes.

QTL mapping identified QTL for Ndfa on seven chromosomes. The GWAS peak identified on Pv09 for Ndfa overlapped with the QTL on Pv09 for Ndfa identified in the QTL mapping study.

Previous studies have reported QTL for Ndfa on Pv04 and Pv10. Using GWAS, QTL mapping and transcriptome profiling, genomic regions and expression candidate genes for SNF have been identified. Once validated, these QTL and genes have potential to be used in marker-assisted breeding to circumvent challenges of phenotypic selection for SNF and accelerate genetic improvement of common bean for symbiotic nitrogen fixation.

Objective 4. Develop phenometric approaches to improve 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 that end, the morphology of a drought tolerant genotype, tepary bean, and a drought susceptible genotype, common bean cultivar *Jaguar*, were examined.

First, the leaf density of both genotypes was measured. Ecologists have observed that species growing in low precipitation areas have *sclerophyllous* leaves—leaves that are small, thick, and leathery; because drought tolerant tepary bean exhibited smaller leaf sizes than susceptible Jaguar or common beans in general, it was hypothesized that tepary bean might also have denser leaves. Multiple detached leaves of Jaguar and tepary were photographed and their leaf areas determined with image analysis software. The detached leaves were also weighed and from these two parameters, leaf density for both genotypes was determined. Jaguar and tepary were not significantly different in leaf density of approximately 0.018 g/cm^2.

Four bean genotypes contrasting in drought tolerance were also tested with assimilation vs. intercellular CO_2 (A-Ci) curves, which can give insight into various parameters that limit photosynthesis. From the analysis, differences in maximum carboxylation rate of rubisco (V_{cmax}) and the electron transport rate (J) were found among the varieties (table X1). V_{cmax} limits photosynthesis under low CO_2 conditions such as drought while J limits photosynthesis under high light conditions. Zorro is only moderately drought tolerant, but it is a highly productive cultivar, so its higher V_{cmax} and J could contribute to its higher productivity and ability to withstand intermittent drought. Tepary is extremely drought tolerant, and its higher J could allow it to withstand the higher light intensities coincident with drought stress without being damaged.

Also integral to this objective is developing new methods of evaluating the stress resistance of different genotypes. A screening method utilizing heat stress has been developed to facilitate this goal. Because drought and heat tolerance share many physiological and genetic pathways, it has been

> ***Ecologists have observed that species growing in low precipitation areas have sclerophyllous leaves—leaves that are small, thick, and leathery; because drought tolerant tepary bean exhibited smaller leaf sizes than susceptible Jaguar or common beans in general, it was hypothesized that tepary bean might also have denser leaves.***

hypothesized that heat could be used to indirectly screen for drought tolerance. Fifteen bean genotypes contrasting for drought tolerance were gathered; successive replications of the 15 genotypes were grown in a growth chamber at 35° C; the temperature was then raised to 40° C and finally to 45° C. After a few days acclimation to the new temperatures, the plants were measured for parameters that respond to stress with a variety of methods: gas exchange, chlorophyll fluorescence, leaf temperature, and qualitative visual assessment. The results show that no significant differences were noted among these genotypes until the most severe stress of 45° C. At that point, drought tolerant genotypes like tepary clearly separated out from susceptible phenotypes, like Jaguar and 553. This heat screening method is a fast, effective, and reproducible way to test many genotypes for drought tolerance specifically and abiotic stress tolerance generally.

Major Achievements

- Project in Uganda has made significant advances towards achieving its breeding objectives, especially in germplasm acquisition and utilization.
- Identified six and five tentative resistance bean sources for rust and CBB diseases, respectively.
- Engaged 326 farmers in on-farm trials that are evaluating and making selections for the utilization of fast cooking bean varieties.
- Identified several sources of drought tolerance in common bean.

Research Capacity Strengthening

The collaborative research has enabled us to improve research capacity at NaCRRI in both breeding activities and human resources. We continued training and mentoring one PhD and two MSc students.

We were also able to train three research assistants and five technicians in Uganda on the use of modern technologies to capture field data. The host country PI in Uganda was supported in attending a common bean disease workshop on angular leaf spot and root rot. Additionally, two short-term trainings were organized for research assistants and technicians in Uganda to strengthen their research capability in data collection as part of the project's breeding management system.

Human Resource and Institutional Capacity Development

Two short trainings were conducted during this year. The first was at NaCRRI Namulonge in Uganda in May 2015 on using Geographic Information Systems (GIS) to capture and map locations where data is collected, which helps in the collection of diseases samples from within the country. Four men and five women participated.

The second training was in Uganda in July 2015 for research assistants and technicians on using of the breeding management system for the integrated breeding platform, a computer-based tool to manage breeding data, and the use of tablets for field data capture. Four men and five women participated.

Achievement of Gender Equity Goals

In Uganda we have ensured representation of more than 30 percent women in all our activities at NaCRRI, with farmers, and in short-term training.

In Zambia we have identified NGOs to partner with who will focus on outreach and technology dissemination among women farmers towards Income Generating Activities as well as seed and grain production for market sales to help elevate income and reduce poverty.

Scholarly Accomplishments

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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)

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Abstract of Research Achievements and Impacts

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 several years, the Bean Technology Dissemination (BTD) project multiplied and distributed seed of improved bean cultivars developed by S01.A4 plant breeders to thousands of farmers in Central America and Haiti.

Seed of multiple disease resistant black bean cultivar XRAV-40-4 and red mottled bean breeding line PR0737-1 was multiplied in Haiti. The small red cultivar Paraisito Mejorado 2-Don Rey, with excellent seed type, disease resistance, and abiotic stress tolerance was released in Honduras. The BGYMV and BCMNV resistant black bean line MEN-2201-64ML from Zamorano had superior performance under drought conditions in Haiti, Nicaragua, and El Salvador. White bean germplasm lines with BGYMV, BCMNV, and rust resistance were released. Red mottled, cranberry, and pinto bean lines with BGYMV and BCMNV resistance are ready for testing in field trials. Black bean breeding lines that combine resistance to BGYMV, BCMNV, and bruchids are also ready for field testing. Angular leaf spot isolates from Honduras and Puerto Rico were found to have high levels of virulence.

Populations are being developed to identify a molecular marker for the *Bgp-1* gene that confers resistance to pod deformation in the presence of BGYMV. Putative markers for bruchid resistance have been identified. 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). Workshops dealing with bean research techniques and seed production were offered at Zamorano.

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). Greater heat tolerance combined with resistance to BGYMV 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 Lab project will address 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 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. BCMNV is also a serious disease in lowland bean production regions of southeastern Mexico. Small red bean breeding lines that combine resistance to BCMNV and BGYMV are currently being developed at Zamorano. BGYMV and BCMNV resistant black and small red bean lines will be 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 will permit the field testing of this seed type in Eastern Africa.

A demonstration garden in Acossaam, Haiti

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 three 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 are expected to be released in Central America and the Caribbean during the next two years.

The project plans to release red mottled, yellow, and white bean cultivars with enhanced levels of disease resistance in Haiti. These seed types are produced in regions where the CRSP project has had less impact. This effort is consistent with the FTF 2011–2015 multiyear 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 BCMNV resistance will be available for Legume Innovation Lab or Feed the Future projects 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 tepary bean and possibly the null phaseolin trait from runner bean. 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 BGYM.

A bean plant evaluation in Haiti

The project will continue to screen germplasm to identify additional sources of resistance to diseases that limit bean production in Central America and the Caribbean.

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 is a potential 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 beans are being used as a long-term effort to introgress these traits into tepary beans.

Because molecular markers are only available for a limited number of traits or only effective in a specific gene pool, there is a need to develop new or more robust markers, particularly for traits of economic importance to bean breeding programs in the tropics. Recent advances by the BeanCAP project, led by North Dakota State University, in sequencing the bean genome and the development of a SNP array and GWAS will facilitate the mapping and development of molecular markers for traits of economic importance, while breeder-friendly InDel markers are a broadly applicable technology. The availability of phenotypic data in appropriate populations is a major factor limiting the development of these markers. This Legume Innovation Lab will assist this effort through the development of the populations and information needed to identify improved markers for traits such as the *Ur-11* gene for rust resistance. Dr. Phil McClean at NDSU will lead the collaborative effort to develop improved molecular markers.

Objectives

1. Genetic improvement of common and tepary beans for Central America and Haiti
2. Develop and implement robust molecular markers for disease resistance genes
3. Institutional capacity building

Technical Research Progress

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

Development, testing, and release of improved bean cultivars
Plant breeders 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 have been conducted in collaboration with national bean research programs and CIAT. Promising lines have been tested throughout Central America

and the Caribbean. Field trials have been conducted to screen bean lines for resistance to angular leaf spot, powdery mildew, and web blight. Testing sites have been chosen to produce reliable results for screening for specific traits.

Leafhopper tolerant line PR1146-138 (left) vs. a leafhopper infested line (right)

Dr. Porch demonstrating how to prepare a leaf sample to test for the presence of a plant pathogen.

Vertical soil tubes in a Zamorano greenhouse

Trial Name	Small red	Small black	Countries
Regional bean adaptation nursery (VIDAC)	64 entries + 2 checks	30 entries + 2 checks	GU, ES, HO, NI, CR, HA
Elite line yield trial (ECAR)	14 entries + 2 checks	14 entries + 2 checks	ES, HO, NI, CR, GU, HA
Regional Rojo de Seda Nursery (VIROS)	52 entries + 2 checks		ES,HO, NI, CR
Bean variety validation trial (COVA)	8 + 2 checks		ES, HN
Regional angular leaf spot trial (ERMAN)	24 entries + 2 checks		ES, HO, NI, CR, GU, HA
Regional web blight trial (ERMUS)	8 entries + 2 checks		ES, HO, CR, GU
Biofortified bean trial (AGROSALUD)	9 entries + 1 check		ES, HO, NI, GU, CR
Regional BNF trial (ERFBN)	8 entries + 2 checks		HO
Regional high temperature trial (ERSAT)	20 entries + 5 checks		HO, CR
Regional drought trial (ERSEQ)	20 entries + 5 checks		HO, CR
Tepary bean adaptation trial (TAT)	19 + 1 check		HO, CR
Regional tepary bean trial (ERTEPARI)	21 entries + 1 check		CR, HO

Table 1. Bean and other grain legume trials distributed to Central American and Caribbean Bean Research Network collaborators during 2014–2015.

Greater tolerance to abiotic stress

Although disease resistance is the primary focus of this project, the performance of bean breeding lines was 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 locations for screening beans for performance in low N soil, for root rot resistance, and at high temperature. 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. They were inoculated with efficient *Rhizobium* strains to allow indirect selection for enhanced BNF.

Bruchid resistance
Considerable progress has also been made toward the development of black beans that combine bruchid and virus resistance. Bruchid resistant bean breeding lines were used to introgress resistance to this pest into commercial seed types

Nodulation on bean plant roots, demonstrated at the Zamorano workshop

A soil: sand system for evaluating nodulation and BNF at Zamorano. In the center of the image (the yellow row) is a line that cannot nodulate and biologically fix nitrogen; the bordering rows are advanced lines selected at Zamorano for enhanced biological nitrogen fixation; they were not fertilized with nitrogen.

(black, small red, red mottled, light red kidney, and yellow) produced in the target countries. A laboratory screening technique developed at the University of Puerto Rico was used to evaluate the resistance of bean breeding lines. The effectiveness of using molecular markers for traits associated with bruchid resistance is under evaluation. An additional breeding objective was to combine bruchid and virus resistance. Bruchid resistant Rojo backcross lines developed in collaboration with Oregon State University and Sokoine University of Agriculture were identified as also having BCMV and BCMNV resistance.

Evaluation of bean diversity panels and identification of new sources of disease resistance
The Middle American (MDP) and Andean Diversity (ADP) panels were screened in Central America and the Caribbean for specific traits, for example, reaction to powdery mildew and angular leaf spot. MDP performance was evaluated in low N environments and screened for resistance to ashy stem blight.

Genetic Improvement of Tepary Beans
Although tepary bean has high levels of abiotic stress tolerance, it is susceptible to such viruses as Bean Golden Yellow Mosaic Geminivirus (BGYMV), Bean Common Mosaic Virus (BCMV), and Bean Common Mosaic Necrosis Virus (BCMNV). 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 tepary breeding lines and to initiate the introgression of virus resistance from common bean into tepary bean.

Tepary trial field

A tepary breeding program was initiated at USDA-ARS-TARS in 2008. Advanced breeding lines developed from these previous breeding efforts have been increased and shared with the collaborators for testing in Tepary Adaptation Trials (TAT). New tepary breeding lines have been generated from crosses between promising large and round seeded genotypes from the CIAT collection and breeding lines selected for disease and abiotic stress tolerance.

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

This project has leveraged the 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. The release of the common bean whole genome assembled sequence allowed for precise localization of each of these markers. The final key element that has facilitated 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, 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
Targets for improved marker development include:

- Bean golden yellow mosaic virus resistance genes and QTL
- Bruchid resistance genes
- BCMV and BCMNV
- Bean rust

For each of these targets, we adopted the same procedure. First, we searched the published literature and communicated personally with breeders, geneticists, and pathologists in both LIL projects to identify genetic materials with contrasting phenotypes (resistance, susceptibility) for the specific disease.

Development of InDel markers

- DNA was isolated from genetic populations or collections of lines with known phenotypes.
- The physical locations of target genes or markers was identified using sequence information.
- InDel marker selection. Once the location of the marker was determined, it was then compared to the InDel database to discover InDel markers that straddle the physical location of the marker. Those InDel markers were then used in PCR amplification to determine which one acts as a definitive marker that is unambiguous in its predictive power.

Examining bean plants at the Zamorano workshop in April 2015.

Objective 3. Institutional Capacity Strengthening

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 to increase production or reduce losses in the target countries.

Informal training

- A workshop was held in Honduras in April 2015 to train technical personnel from Central America and the Caribbean on bean research techniques with the goal of improving the quality of field research. Topics included the development and management of field trials, breeding and selection methods, field evaluation techniques, research with *Rhizobium*, participatory plant breeding and agroecological techniques.
- The project received Institutional Building Funds to conduct a workshop at Zamorano in August 2015 to discuss with technical personnel from Central America and the Caribbean techniques needed to produce, process and store high quality seed stocks.

Major Achievements

- XRAV-40-4, which combines resistance to BGYMV, BCMV, and BCMNV and is adapted to the humid tropics, was developed and released cooperatively by UPR and UNL Agricultural Experiment Stations, the USDA-ARS, the Instituto Dominicano de Investigaciones Agropecuarias y Forestales (IDIAF), the Escuela Agrícola Panamericana, Zamorano, Honduras, and the National Seed Service of the Ministry of Agriculture of the Republic of Haiti.
- The light red cultivar Paraisito Mejorado 2- Don Rey, which carries BGYMV and BCMV disease resistance and has greater adaptation to low soil fertility, was released in Honduras.

- White bean lines were released that combine the *bgm-1* gene and the SW12 *QTL* for resistance to BGYMV, the *I* and *bc-3* genes for resistance to BCMV and BCMNV and resistance to a wide range of rust races.
- The red mottled bean line PR0737-1 that combines resistance to BGYMV, BCMV, and BCMNV was released as improved germplasm. Seed is being multiplied in Haiti and will be formally released as a cultivar.
- The small red bean breeding line IBC-301-204, selected at Zamorano for resistance to BGYMV, BCMV, and tolerance to low fertility trials, was released in Nicaragua as *INTA Centro Sur*.
- The small red bean breeding line SJC 730-79, selected at Zamorano for resistance to BGYMV, BCMV, and tolerance to high temperatures, was released by CENTA in El Salvador.
- Release of tepary bean selection Tep-22 that combines resistance to common bacterial blight, rust, and tolerance to heat and drought.
- Through the USDA-FTF project and a USDA Postdoc, the Tepary Diversity Panel (TDP) composed of 320 accessions was developed and genotyped.


Promising PR lines in Chimaltenango

Research Capacity Strengthening

LIL plant breeders assisted bean research programs in Guatemala and Haiti to develop their capacity to produce populations and test breeding lines that will lead to the release of improved bean cultivars and contribute to the long-term sustainability of bean breeding activities in the region. The ICTA bean research team developed populations and evaluated bean breeding lines in the field and using marker-assisted selection to identify lines with resistance to anthracnose. Dr. Porch provided bulk populations of black beans to Haiti to give National Seed Service researchers experience making field selections and managing breeding lines.


Damien Bean Evaluation in Haiti.

The project received Institutional strengthening funds to continue to support the bean research network in Central America and the Caribbean. These funds permitted bean researchers to attend the PCCMCA annual meeting to share their research and meet with bean researchers to plan collaborations. The project collaborated with INTA to commemorate the International Year of Pulses at the PCCMCA meeting in Costa Rica.

This project continues to collaborate with many CRSP alumni institutions, extending the potential impact of LIL research and generating valuable information to the global bean research community. A few of the collaborative research activities are listed below:

- Bruchid resistance research with Paul Kusolwa at Sokoine Agricultural University in Tanzania
- Evaluation of red mottled and black bean breeding lines by IDIAF in the Dominican Republic
- Regional performance trials (SISTEVER) in Nicaragua, El Salvador, and Costa Rica
- Evaluation of Andean and pinto bean lines and bulked breeding populations in Angola
- Rhizobium Inoculant production in Haiti

Human Resource and Institutional Capacity Development

Short-Term Training

Purpose of Training	Bean research techniques	Bean disease workshop	Technologies for bean seed production
Type of training	Workshop	Workshop	Workshop
Countries benefitting	Costa Rica, El Salvador, Nicaragua, Honduras, Guatemala, Haiti	Angola, Argentina, Brazil, Dominican Republic, Ethiopia, Kenya, Malawi, Mozambique, Puerto Rico, South Africa, Tanzania, Uganda, USA, Zambia	Costa Rica, El Salvador, Nicaragua, Honduras, Guatemala, Haiti
Location and dates of training	Honduras April 2015	South Africa July 2015	Honduras August 2015
Number receiving training (by gender)	3F, 13M	22F, 43M	1F, 16M
Home institution(s)	Zamorano	USDA-ARS, ARC Grain Crops Institute	Zamorano
Institution providing training	Zamorano, UPR, USDA-ARS	Various	Zamorano, UPR

Table 2. Summary of short-term training of Legume Innovation Lab project S01.A4 during FY15.

Scholarly Accomplishments

Beaver, J.S., J.C. Rosas, T.G. Porch, M.A. Pastor-Corrales, G. Godoy-Lutz and E.H. Prophete. 2015. Registration of PR0806-80 and PR0806-81 white bean germplasm with resistance to BGYMV, BCMV, BCMNV and rust. *J. Plant Reg*. 9:208–211.

Estévez de Jensen, C., T.G. Porch and J.S. Beaver and O. González. 2015. Root rots of common and tepary beans in Puerto Rico. Common Bean Disease Workshop on Angular Leaf Spot and Root Rot. Protea Kruger Gate. Skukuza, South Africa, July 20–23, USDA/ARS, *Proceedings*, p 48.

Porch, T., Hart. J., Estévez de Jensen, C, 2015. Response of the Andean Diversity Panel to Root Rot in a Root Rot Nursery. Common Bean Disease Workshop on Angular Leaf Spot and Root Rot. Protea Kruger Gate. Skukuza, South Africa, July 20–23, USDA/ARS, *Proceedings*, p 58.

Rosas, J.C., I. Rodriguez, A. Llano, A. Clará, J.C. Hernandez, J.S. Beaver and S. Beebe. 2015. Resultados del SISTEVER de frijol de grano rojo. Paper presented at the 2015 meeting of the PCCMCA held in Guatemala City from 4 to 7 May 2015.

Rodriguez, J.C. Rosas, J.S. Beaver, T. Porch, S. Beebe and J.P. Lynch. 2015. Evaluación de germoplasma de frijol común para la tolerancia a las altas temperaturas. Paper presented at the 2015 meeting of the PCCMCA held in Guatemala City from 4 to 7 May 2015.

Professional Recognition

Dr. Juan Carlos Rosas received the 2015 AGEAP (Zamorano Alumni Association) recognition for his contributions to Pan-American agriculture and Zamorano University.

Consuelo Estevez de Jensen received an USDA/ARS Certificate of Appreciation for outstanding efforts to characterize bean germplasm for enhanced BNF and root rot response for Feed the Future countries in support of the Feed the Future Grain Legumes Project, South Africa, July 2015.

The University of Puerto Rico Bean Research Team (Consuelo Estevez, Mildred Zapata, and James Beaver) received recognition for “Outstanding Dedication and Contribution to Research and Innovation Endeavors” during 2014–2015 at the *Research and Innovation as Accelerators of New Opportunities in Puerto Rico* symposium held on the Mayaguez, Puerto Rico Campus on 15 May 2015.

Genetic Improvement of Cowpea to Overcome Biotic Stress and Drought Constraints to Grain Productivity

(SO1.A5)

LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

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COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

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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), Ghana

Ndiaga Cisse, Centre National Recherches Agronomie, Bambey, Institut Senegalais de Recherches Agricole (ISRA) & CERAAS, Senegal

Abstract of Research Achievements and Impacts

A panel of cowpea accessions was used with uniform test protocols for field and screen house testing to characterize resistance to aphids and to identify cowpea aphid biotypes in three African and one U.S. locations. Cowpea populations segregated for insect resistance (pod bugs, Burkina Faso; flower thrips, Ghana and Senegal; aphids, Ghana and California) were advanced, phenotyped, and genotyped for QTL discovery for use in marker-assisted breeding.

Five large, white-seeded CRSP cowpea varieties were formally released in Senegal under the names *Lisard, Thieye, Leona, Kelle* and *Sam* after multiyear on-farm demonstration trials, with Breeder and Foundation seed produced and distributed to farmers' organizations. In Burkina Faso, four prerelease CRSP cowpea lines were selected from on-farm trials and on-station Breeder seed produced in anticipation of their release as improved varieties in 2016.

In California, advanced lygus and disease resistant blackeye lines were on-farm and on-station performance tested. Five African students engaged in degree training programs (three PhD, two MS) in the project. Capacity strengthening awards from the MSU management entity supported development of screen houses, an irrigation system (Ghana and Burkina Faso), and cowpea seed storage (Senegal). Continuous short-term training occurred through iterative data analysis and interpretation cycles using the phenotype and genotype data from each host country. A training/planning workshop in 2015 at UCR for scientists from Ghana, Senegal, Burkina Faso, Nigeria, and Mozambique utilized molecular breeding modules.

Project Problem Statement and Justification

The project's focus is to

1. Discover insect tolerance and resistance QTL for cowpea breeding
2. Increase African and U.S. cowpea productivity by improved varieties with resistance to insect stresses, drought tolerance, or disease resistance
3. Expand farmer marketing opportunities with improved cowpea varieties
4. Provide training and capacity building in modern cowpea breeding

The project is aligned with the following FTF research strategic priorities:

1. Crop resistance to heat, drought, salinity, and flood
2. West African Sudano–Sahelian systems emphasizing insect-resistant cowpea
3. Grain legume productivity

Strategically, our partner countries, Ghana, Senegal, and Burkina Faso, represent primary agroecologies for cowpea production in the Sudano–Sahel region.

The project uses genomics and modern breeding to improve cowpea yield by targeting insect tolerance and resistance. By leveraging genomic resources developed with the 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), midflowering 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 early generation populations with target traits, providing valuable starting points for breeding.

A cowpea plant infested with Aphids.

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 and cooking and processing characteristics. Regionally adapted cowpea varieties with large white grain and large rough brown grain with resistance to pests would increase the marketing opportunities of cowpea farmers and traders in both West Africa and the United States.

Objectives

1. Discover QTL for insect resistance and apply in molecular breeding for target regions in West Africa and the United States.
2. Complete release and validation of advanced cowpea lines developed under the Pulse CRSP in Burkina Faso, Senegal, and the United States
3. Increase capacity of NARS in Burkina Faso, Ghana, and Senegal to serve the cowpea sector.

Technical Research Progress

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

1.1 Aphid resistance

We tested the genetic relatedness of five sources of cowpea aphid resistance. Field observations in Africa and California indicated 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 again in 2015 (see table 1). Uniform screens in field locations across all project NARS (Burkina, Ghana, Senegal) and California were conducted in 2014 in field plots or screen houses, with four-fold replication, using standard resistance assessment scales across all test sites. Additional germplasm lines were included in the screening sites to search for more sources of resistance. This multisite phenotype screening for resistance response was repeated in FY15 to provide a minimum of two years of data.

In 2015 in Senegal, the aphid population did not become sufficiently established with uniform infestation in the field to discriminate between genotypes because of a wet season with heavy rain; however, enough seeds were produced for later experimentation.

In Ghana, the seedling stage screening of the aphid resistance panel at SARI found IT97K-556-6, KvX-295-2-124-99, SARC-1-57-2, 58-77, and CB27 to be resistant to the cowpea aphids in northern Ghana. In testing the mode of inheritance and the genetic relatedness of these lines, F1 populations have been developed between each of these lines with Apagbaala (an aphid-susceptible, popular variety in Ghana) and, in addition, each of these lines found to be resistant has also been crossed with one another. These populations are currently being advanced to the F2 at SARI. They will be genotyped and phenotyped to determine the mode of inheritance of the aphid resistance source in each of the resistant lines and to determine the uniqueness of the aphid resistance gene(s) in each of these lines.

Name	Type	Origin
58-77	Aphid resistant source	ISRA
INIA19	Aphid resistant source	MSU
IT97K-556-6	Aphid resistant source	IITA
KN1	Aphid resistant source	INERA
KvX-295-2-124-99	Aphid resistant source	INERA
SARC-1-57-2	Aphid resistant source	SARI
TVNu-1158	Aphid resistant source	IITA
APAGBAALA	Aphid susceptible check	SARI
BAMBEY21	Aphid susceptible check	ISRA
CB27	Aphid susceptible check	UCR
IT82E-18	Aphid susceptible check	IITA
VITA7	Aphid susceptible chzeck	IITA

Table 1. Details of sources of resistance to the cowpea aphid for the differential panel for determining resistance uniqueness and aphid biotype differences.

We are working with Drs. Pittendrigh and Tamo *(IPM-omics: Scalable and sustainable biological solutions for pest management of insect pests of cowpea in Africa* [SO1.B1]) in characterizing the aphid isolates representing the different aphid populations at each location, which will be especially valuable if aphid biotypes are delineated on the cowpea resistance sources.

Samples of aphids were collected and stored for DNA extraction, with a view to developing a DNA sequence-based fingerprint to distinguish the isolates. For example, in Burkina Faso aphids were collected from three diverse cowpea production zones. New segregating populations and some existing ones between aphid resistant and susceptible parents will be used to phenotype screen for QTL discovery. We finished a QTL discovery effort for aphid resistance in IT97K-556-6, identifying two resistant QTLs.

Phenotypes of resistance panel entries infested with aphids at SARI, Ghana.

Apagbaala, an aphid susceptible variety in Ghana).

In Ghana we have an F7 population between a susceptible elite line and resistance donor KvX295-2-124-99. This population was genotyped and phenotyped in FY15 for QTL mapping. From the wild donor IITA line TVNu1158, a RIL population has been developed for mapping QTL and is currently being genotyped using the 60K SNP iSelect by UCR.

1.2 Flower thrips resistance

In recent work on QTL discovery, we identified and SNP-mapped loci (Cft-1 and Cft-2) for flower thrips tolerance donated by Sanzi in the cross Sanzi x Vita 7; 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, the populations 58-77 x Yacine and Sanzi x Vita 7 were field-screened for flower thrips tolerance with two planting dates at Bambey.

In Senegal the different tolerance sources in Sanzi, 58–77 and Tvx3236 were intercrossed in all combinations by Dr. Cisse in FY14 and each of these populations was advanced to the F3 in FY 2015. For breeding purposes, the F1 of Sanzi x 58-77 was crossed to Yacine and to the new large seeded varieties. M3 generations of Yacine generated through mutagenesis were evaluated under a no-spray nursery at Bambey for flower thrips reaction.

At SARI, Ghana, Dr. Kusi received seed in FY15 of the two RIL populations, Sanzi x Vita7 and Yacine x 58-77, from Senegal to be phenotyped for QTL refinement for flower thrips tolerance. Given the limited seeds per line received, the populations were planted to increase the seeds and so the thrips phenotyping was not vigorously carried out. Field preparation is currently in progress to plant the populations under spray and nonspray conditions for vigorous thrips tolerance phenotyping. The aim is to combine the phenotyping data sets from Senegal and Ghana for improved QTL mapping of the thrips tolerance loci.

In Ghana, three Sanzi-derived F7 populations segregating for seed color and flower thrips resistance are being evaluated for QTL discovery and breeding. One parent is the variety Songotra, a high yielding black-eye resistant to Striga but still thrips sensitive. A second parent is SARC1-57-2, which carries aphid resistance. The SARI team is phenotyping these populations. The 280 single-seed derived F7 families were leaf sampled and the samples sent to UCR where they were DNA-extracted and sent for SNP genotyping using the Illumina iSelect platform.


Cowpea seedlings growing in the screen house for insect pest testing.

The seeds produced from each of the single-seed descent plants were phenotyped for both flower thrips and Striga resistance. The populations have now been classified into individuals that recorded Striga emergence on the field and those that did not record Striga emergence. The individuals that did not record a single Striga emergence are currently being prepared for screening in pots infested with Striga seeds to validate the field results by washing the root to check if there were no attachment underground. The thrips phenotyping was not vigorously done because we also wanted to produce more seeds. Therefore, each family was flower-sampled at 7 days after insecticide spray to generate preliminary data on assessment of the lines with thrips resistance. Now with enough seeds available, the populations are being prepared to be planted under spray and nonspray conditions for vigorous thrips phenotyping at Tamale and Manga. These data will be used with the SNP genotyping for QTL mapping.

1.3 Pod-sucking bug resistance

The Heteropteran Coreid pod-sucking bugs are a major yield suppressor in Burkina Faso, Ghana, and neighboring countries. We have not yet identified genes or QTL for resistance to pod-sucking bugs but resistant cowpea accessions are available. We started to use biparental resistant x susceptible segregating populations in FY14 to map QTL and initiate their selection as a new breeding target. This work is a focus of effort in Burkina Faso. A primary tolerance source is IT86D-716; pods on F2 plants were phenotyped in FY15 to identify the underlying QTL, using standard screens of young pods in petri dishes to score bug viability and fecundity. The 2014 screening was not successful. New combinations were made in 2015. Four different F2 and BC1F1 populations are available. The rephenotyping is planned for February 2016.

Examining the cowpea seedlings for insect pests in the screenhouse.

Additional potential tolerance donor lines were included in the initial phenotyping screens in FY14, including those in the pedigree of resistance donor IT86D-716, to broaden the knowledge base and potentially identify additional sources of tolerance. 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 have been genotyped through LGC Genomics and the F2 and F3 populations will be phenotyped in FY16 for pod bug resistance in Burkina Faso. Using leaf samples collected from phenotyped plants in Burkina Faso, single F2 plants and F3 family bulks consisting of a minimum of 12 individual plants will be genotyped. The phenotype and genotype data from the F2 and F3 generations will be used for QTL discovery with the ICI Mapping program, which will be conducted at UCR.

We collaborated with Drs. Pittendrigh and Tamo for the three insect groups (aphids, thrips, pod bugs) to utilize our project trial sites to collect insect samples for use in molecular characterization of the insect populations. Collections will be made at all test locations. We have tested a protocol for insect DNA collection, in which insects are placed in plastic bags with silica gel packs to dry the insect samples and preserve the DNA.

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

2.1. We continued to use our genotyping capability to advance the BT gene introgression for *Maruca* resistance with our SNP marker panel. Genotyping 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. In Burkina Faso BC3 were genotyped in FY14. In FY15, populations were advanced to the BC3F5 and BC5F3 stages and leaf samples were collected and are awaiting SNP genotyping. In FY15, trials were conducted 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. The genotyping on sampled plants determined those carrying resistance with the highest level of recurrent parent genotype. Ghana BC2 progenies from FY14 were advanced in FY15 and leaf-sampled for SNP genotyping on the next generation of breeding lines. Leaf samples from young screen house grown plants in the phenotyping and crossing blocks were used for DNA extraction in Burkina Faso and Ghana, and then SNP assayed by LGC Genomics.

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

In Senegal, five large white grain type cowpeas were submitted as candidates for release by the national variety release committee in FY14. They were performance tested in 20 on-farm demonstration trials in the main season FY13 and the data combined with performance data from 2011 and 2012 to support the formal release. In 2015 the five new lines, *ISRA-3178, ISRA-3201, ISRA-3205, ISRA-3211,* and *ISRA-3217*, were registered, respectively, as the new varieties *Lisard, Thieye, Leona, Kelle,* and *Sam*. Additional Breeder and Foundation seeds were produced during the 2015 off-season on 2000 m2 for each variety; about 500 kg of seeds for each variety were obtained. Seeds were provided to several farmers' organizations

Breeding lines growing in testing fields are examined by several members of the project team and to the extension service for large-scale demonstration to generate demand and for Certified seed multiplication.

In Burkina Faso, 20 prerelease CRSP advanced lines developed by Dr. Drabo were on-farm performance tested in 2013; a subset of the best nine lines were re-evaluated in 2014. Multilocation 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 will be re-evaluated off-season in FY 2016, emphasizing yield and grain quality, plus any disease susceptibility. About 20 kg of Breeder seeds of each of these lines is now available at the INERA Saria Station, and will be used to initiate Foundation seed production in the FY 2016 off-season.

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. The most promising lines (combination of yield, seed quality, and resistance) from 2014 trials were chosen for performance testing in May 2015 in Tulare Co. with four lines and June 2015 at the Kearney station with five lines. Harvesting, threshing, and seed cleaning was under way at the time of reporting.

The Senegal and Burkina Faso releases will represent tangible project outputs and offer the opportunity for tracking along the impact pathway as new releases that will be entering the seed multiplication and distribution process in each country. During the 2015 main rainy season, each of the five new releases were multiplied for additional Foundation seed production. The resulting products will be provided to Certified seed producers, including new farmer organizations, for increase and demonstration in 2016.

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

Short-Term Training


A healthy cowpea harvest in Burkina Faso

Molecular breeding for trainee breeders and NARS scientists has been conducted. Continuous short-term training was conducted through iterative data analysis and interpretation cycles using the phenotyping and genotyping data generated by each of the three host country partner teams.

Because the molecular breeding approach requires a combination of hands-on experience with self-generated data sets, an intensive training workshop was convened at UCR in March 2015 for all levels of breeders to improve knowledge, skills, and problem-solving abilities. Additionally, because the technologies underlying genotyping capability are frequently enhanced and upgraded, periodic instruction for both trainees and experienced breeders from the HC NARS is also needed.


A late damping off caused by *Pythium sp.*

Training materials and protocols used by the NARS breeders were also used to train the technical staff in the NARS programs after NARS breeders had been trained fully on the standardized electronic field book, leaf assay, and field phenotyping protocols.

Major Achievements

Formal release of five large white-seeded CRSP cowpea varieties (*Lisard, Thieye, Leona, Kelle,* and *Sam*) was completed in Senegal following the final performance testing in on-farm trials. Foundation seed of each variety was then produced by ISRA and distributed to farmers' organizations for Certified seed development.

Research Capacity Strengthening

The Legume Innovation Lab Management Office granted funding to renovate the 1960s cold room used for seed conservation at the ISRA Bambey research station in Senegal to insure adequate temperature and humidity maintenance as required for cowpea germplasm conservation, with the necessary equipment installed in 2015.

Funds were also granted to INERA, Burkina Faso, to enhance breeding activity at the Kamboinse Research Station through the development of an irrigated field for off-season activities (e.g., crosses, advancing lines, breeder seed production). A one-ha plot is being managed following implementation of the new drip-irrigation system. Restoration or building of one screen house at Kamboinse Research Station, one at Saria Research Station, and one at SARI, Ghana, were also funded by LIL and completed in 2015. The screen houses promote successful crosses; protect advance breeding lines from insect, rodent, and rabbit damage; and allow the multiplication of breeder seeds during the Harmattan period. The Ghana facility includes a 16m x 8m screen house fitted with a 500-gallon polytank reservoir for supply of water, a metal frame covered with insect proof net and a polythene sheet for sealing the roof to prevent rain, and benches 80 cm to one m high for growth containers.

Human Resource and Institution Capacity Development

Short-Term Training

Intensive training on the molecular breeding approach and genotyping was conducted at UC–Riverside in March 2015 for 12 African scientists/students (11 men, one woman) from Ghana, Senegal, Burkina Faso, Nigeria, and Mozambique.

Two two-day intensive field-based trainings on cowpea production and seed storage techniques were conducted at INERA, Burkina Faso, in October 2014, for 45 women and 70 men.

> *Formal release of five large white-seeded CRSP cowpea varieties (Lisard, Thieye, Leona, Kelle, and Sam) was completed in Senegal following the final performance testing in on-farm trials. Foundation seed of each variety was then produced by ISRA and distributed to farmers' organizations for Certified seed development.*

Achievement of Gender Equity Goals

In Ghana, the SARI team trained 480 women from women's farmer groups involved in cowpea production and marketing from 15 communities. The project team collaborated with CARE international Ghana in the training. The main training topics covered current research on developing varieties resistant to insects and drought and integrated strategies to manage insect pests, diseases, and drought.

Women farmers and their families

In Senegal, training of the farmers' organization RESOPP (Le Réseau des Organisations Paysannes et Pastorales du Sénégal/Network of Farmer and Livestock Organizations of Senegal) on seed production and postharvest operations continued, including more than 200 women producers. In Burkina Faso, 190 women producers were trained on cowpea production and seed storage.

Scholarly Accomplishments

Huynh, B.L., Ehlers, J.D., **Ndeve, A.,** Wanamaker, S., Lucas, M.R., **Close, T.J., Roberts, P.A.** 2015. Genetic mapping and legume synteny of aphid resistance in African cowpea (Vigna unguiculata L. Walp.) grown in California. *Molecular Breeding* 35:36 (1–9). DOI 10.1007/s11032-015-0254-0

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Huynh, B.L., Matthews, W.C., **Ehlers, J.D.,** Lucas, M.R., Santos, J.R.P., **Ndeve, A., Close, T.J., Roberts, P.A.** 2015. A major QTL corresponding to the Rk locus for resistance to root-knot nematodes in cowpea (*Vigna unguiculata* L. Walp.). *Theoretical and Applied Genetics*. In press.

Cisse, N. et al. 2015. Formal release of five new cowpea varieties in Senegal with large white seed-type and disease resistance. Variety name registrations Lisard, Thieye, Leona, Kelle and Sam.


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IPM-omics: Scalable and Sustainable Biological Solutions for Pest Management of Insect Pests of Cowpea in Africa

(SO1.B1)

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Eustache Biaou, INRAB-Benin; replacement for Mr. Leonard Hinnou

Abstract of Research and Capacity Strengthening

Over the past year we advanced our understanding of and solutions for the major pests of cowpeas in Benin, Niger, Burkina Faso, and Ghana. We have characterized pest populations through both field-level and molecular tools, specifically focused on mitochondrial polymorphisms. Solutions to these pest problems have been developed, including tangible solutions from our biocontrol agent pipeline and a combined neem and *Maruca*-specific viral spray.

We have continued to develop and to investigate the use of educational animation tools with voice overlays in local languages as a scalable system to create and deploy locally sourced pest control solutions based on our research. Our capacity building efforts have included undergraduate and graduate training in host country programs and cross-training of host countries' technicians. We continue to test our animated educational approach, including ICT training sessions and the release of an Android App that allows collaborating organizations to easily access and use these materials in their educational programs. We collaborated with Dr. Maredia's team at MSU and Dr. Mazur's team at ISU on social science questions related to scaling technologies and approaches for pass off to other groups.

> *We have developed scalable educational solutions on pest control strategies in local languages and at all literacy levels, and are exploring pathways to pass these off to other groups for deployment in their educational programs.*

Project Problem Statement and Justification

Insect pests of cowpeas, which are arguably their greatest biotic constraint, dramatically reduce yields for cowpea farmers in West Africa, many of whom live on less than $2 per day. The major pests of cowpea in the field in northern Nigeria, Niger, Ghana, and Burkina Faso include the legume pod borer, *Maruca vitrata Fabricius*, the coreid pod-bugs (two types), a groundnut aphid, and thrips.

The project focuses on a three-step approach: defining the pest problems, developing appropriate pest control solutions, and exploring the scaling of these solutions. We have continued to develop an in-depth understanding of the pest populations through field experiments and molecular tools that characterize and compare pest populations. We have developed solutions that will allow for the development of local cottage industries that can produce biopesticides for local sale and use, facilitating the potential for local value chains in the development and sale of ecologically friendly pest control solutions.

We continued to investigate biological control agents in our biocontrol pipeline and have promising candidates for scaling in the field and approaches to scale their release in a cost-effective manner. Additionally, we have developed scalable educational solutions on pest control strategies in local languages and at all literacy levels, and are exploring pathways to pass these off to other groups for deployment in their educational programs.

In terms of capacity building, we have been working with NGOs and local companies to pass off our outcomes, have continued undergraduate and graduate training, and established a cross-country technician training program to facilitate capacity in biocontrol agent rearing and release and biopesticide development, deployment, and pass-off to local commercial and noncommercial entities.

Technical Research Progress


Aphids on cowpea leaf

Over the past 12 months we have researched, developed, implemented, and performed and analyzed datasets to determine the potential 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. As part of that donor community buy-in, the Bill and Melinda Gates Foundation has funded outcomes of our past efforts on *M. vitrata* (that grant's objectives do not overlap with the LIL grant). Our objects emerge from the following vision, called *IPM-omics*:

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

We integrate these steps with institutional capacity building, which is integral to the overall process.

Objectives

1. Define the pest problems: (1) scouting, field experiments, 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. Complete release and validation of advanced cowpea lines developed under the Pulse CRSP in Burkina Faso, Senegal, and the United States
2. Appropriate solutions. A biocontrol and biopesticide pipeline to develop a series of environmentally and economically appropriate pest control solutions.
3. Scaling of solutions. Exploring Solutions and mechanisms to effectively deploy them in a cost-effective and sustainable manner. Three solution categories: direct release into the environment and natural establishment, educational solutions, private sector and NGO involvement.
4. Capacity building

Technical Research Progress

Objective 1. Define the pest problems: (1) scouting, field experiments, 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

1. The IITA, INERA, INRAN, CRI, and SARI teams performed surveys of the pest populations during and outside of the cowpea cropping cycles. Insects found on diverse alternative host plants were stored in RNAlater or 70 percent ethanol and sent to UIUC for molecular analyses. Additionally, the INERA team established experiments to understand the pest populations that occur in the dry season in places where an extra cycle of cowpea could be planted where irrigation is possible. All of these studies continue.

2. In Ghana (from the SARI team), the results were as follows:

- Field studies were conducted at the Savanna Agricultural Research Institute (SARI), Nyankpala, Tolon district, northern region, Ghana, between July and September 2014 to identify the major insect pests of cowpea, using cowpea variety IT90K-277-2. The results indicated that leafhoppers, Aphis, thrips, *Maruca vitrata*, and pod sucking bugs are the major pests. The thrip population was found to increase with the season and peaked with the rain in September. The incidence of *M. vitrata* and pod sucking bugs was low.
- Surveys were conducted in farmers' fields in 2015; high populations of *M. sjostedti*, *M. vitrata*, and *C. tomentosicollis* were high in Krachi West and the West Gonja districts that are farther south of Nyankpala in the Tolon District.
- As in FY 2014, the following were identified as the alternative hosts of *M. sjostedti* and *M. vitrata*: *Grycine max, Cajanus cajan, Mucuna cochinchinensis, Canavalia ensiformis*, and *Tephrosia*.

The IITA, CRI, INERA, and INRAN teams also continued to produce this type of important baseline data.

1.2 Molecular Analyses of Pest Populations

The project team received pest populations for molecular analysis of insects collected from numerous host plant populations for all species tested, across Benin, Niger, Burkina Faso, and Ghana from IITA. The specimens were stored at -80°C and the DNA extracts were shipped to UIUC for further molecular analyses. Similar sample collections of insects were received from our teams in Burkina Faso, Niger, and Ghana.

Researcher Manu Tamo Inspects *Tephrosia candida* plants for parasitoids of flower thrips. Although the parasitoids were released several years ago, their populations are regularly monitored throughout the year to assess their ongoing impact in the region.

Molecular analyses (SNP and microsatellite analyses) are continuing at UIUC; however, this past year we focused more intensely on SNP analysis of mitochondrial genes since we developed a protocol that allows us to determine the relationships between the populations that will be more useful. One additional series of experiments included populations of aphids collected by the UC-Riverside team on different lines of cowpeas. We have been comparing these populations of aphids to determine if they are distinct biotypes.

1.3 Computational Modeling, GIS systems and Online Systems

The UIUC 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 Dr. Tamo's graduate students to better characterize pest populations. The IITA and UIUC teams continue to explore the use of GIS systems with which to couple our other datasets.

The UIUC team is continuing to summarize the published papers for a website that will be online at the end of the 2015.

1.4 Insect Biology – Sex and Aggregation Pheromones for Pod Sucking Bugs

Olfactometric studies have confirmed previous observations that adult males of the coreid bug produce pheromones that attract the egg parasitoid *Gryon fulviventre*. The student who carried out this research will use an *icipe*-ARPPIS PhD fellowship to carry out the chemical ecology part of his thesis at *icipe* in close collaboration with IITA and will compare pheromone profiles of West, Eastern, and Southern Africa populations of *C. tomentosicollis* and possibly other congeneric *Clavigralla* species, which will be matched by population genetic studies.

Based on the evidence that female egg parasitoids *G. fulviventre* use olfactic cues emitted by adult male *C. tomentosicollis* for locating egg masses in the field, we have developed small field cages that contain the optimum number of *C. tomentosicollis* males, as assessed in previous experiments. The cages have been tested in the field using sentinel egg masses of *C. tomentosicollis* that were parasitized by the parasitoid *G. fulviventre* after 48 hours exposure. This experiment is now being carried out at a larger scale with different treatments to compare parasitism levels due to the attraction of male aggregation pheromones with the naturally occurring parasitism levels, if no pheromones are present. The experiment was started in the second cropping season and will be harvested mid-November.

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

2.1 Novel Maruca Parasitoids Available for Screening

Upon delivery of an official release permit from the Minister of Agriculture, we began conducting experimental releases of the pod borer parasitoid *Therophilus javanus* MSc study examining the details of its host-finding behavior. We successfully recovered parasitoid pupae from *Sesbania cannabina* and cowpea in confined cages in the screen house at IITA–Benin. Confined field cage releases were established during the second cropping season and will be inoculated with different densities of the parasitoid on experimental fields at the IITA–Benin station.

Wasp release in Benin

At the same time, a PhD study has started looking at maternal factors responsible for the parasitic success in *T. javanus*. First observations targeted the specific organs of the female genital tract, particularly the venom gland, whose ultrastructure indicates it is of type 2 as observed in Braconidae. There was also no sign of virus or virus-like particles in the ovaries of this parasitoid, as opposed to the previously studied *Apanteles taragamae*. This parasitoid is able to discriminate already-parasitized larvae, and there is a high probability that the Doufour's gland might be involved in secreting marking volatiles. The study confirmed previous observations that *T. javanus* females prefer two- and three-day-old *M. vitrata* larvae for oviposition.

2.3 PCR Techniques for Detecting Endophytic Strains of Beauveria bassiana Available

Three PCR primers available for the detection of *Beauveria bassiana* were tested: $SCA14_{445}$, $SCA15_{441}$, and $SCB9_{677}$. $SCB9_{677}$ proved the best for the Beauveria bassiana Bb115 strain, following the standard methodology of incubating the culture broth with conidia and extracting the DNA from the mycelium. Attempts to re-isolate *Beauveria bassiana* mycelium directly form plant tissue has proven, however, to be difficult and unreliable to date, but efforts are continuing in this direction, e.g., by designing more robust and Bb115-specific SCAR primers.

A controlled wasp release

2.4 Genetic Improvement of Cowpea to Overcome Biotic Constraints to Grain Productivity (in collaboration with the UCR Cowpea Breeding Team)

This activity was conducted in Burkina Faso with the INERA team and in Niger with the INRAN team screening for resistance or tolerance to *Clavigralla tomentosicollis* and aphid attack. Aphids were collected in three agroecological zones: Sahelian, Sudano–Sahelian, and Sudanian to screen 10 cowpea varieties from Botswana (B 301), Burkina (KN-1, NS-1, NS-Farako-bâ, and KVX 295-2-124-99), Cameroon (N°2300), Ghana (SARC1-91-1 and SARC1-57-2), Nigeria (IT97K-556-6), and the United States (CB27). From all of these varieties (all agroecological zones), IT97K-556-6 was recorded as resistant or tolerant to aphid attack. This study also showed the existence of two strains of aphids in Burkina Faso. Molecular characterization is still needed. F1s from the cross between susceptible plant (tiligre) x KVX 299-2-124-99 are ready to screen. The INRAN team in Niger screened more than 10 varieties of cowpeas thought to have some level of insect tolerance to *Clavigralla tomentosicollis, Maruca vitrata*, and aphid.

Objective 3. Scaling of solutions. Exploring solutions and mechanisms to effectively deploy them in a cost-effective and sustainable manner. Three solution categories: direct release into the environment and natural establishment, educational solutions, and private sector and NGO involvement.

3.1.1. Maruca parasitoids (IITA)

With regard to scaling *M. vitrata* parasitoids, we are on track with establishing rearing colonies for *T. javanus* and *P. syleptae* at the INERA labs in Burkina Faso. Experimental releases of both natural enemies are being prepared using satellite pictures/GIS and ecological information on suitable host plant habitats. They are scheduled at the onset of the dry season in November 2015 on patches of natural vegetation.

Close-up of wasp

3.1.2. Thrips parasitoid available for scaling up (IITA, INERA, and INRAN)

According to schedule, pupae of the thrips parasitoids *Ceranisus femoratus* were collected on patches of *Pterocarpus santalinoides* and *Lonchocarpus sericeus* in Southern Benin and hand-carried to the INERA labs at Farokoba, Burkina Faso, where adult parasitoids were subsequently released on *Tephrosia* candida and other host plants bearing populations of flower thrips. Recapture surveys to assess establishment are planned at the onset of the dry season in November 2016.

3.1.3. Feasibility of storing Maruca virus both as liquid and solid substrate (IITA)

The viral solutions kept for six months in the deep freezer at -18° C and in a normal fridge at 4° C were evaluated in the experimental fields at the IITA station. As observed in the lab studies, the field evaluation indicated no significant differences in their activity, with a 63.2 and 48.8 percent reduction of the *M. vitrata* larval population for 4° C and -18° C treatments, respectively, as compared to the unsprayed control.

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

Locally produced Neem oil being poured from a portable bottle

In Benin, we have established some 54 demonstration plots in farmers' fields covering the whole country, and reaching an estimated 10,000 farmers. Treatments consisted of the targeted MaviMNPV and the emulsifiable neem oil mixture, the neem oil alone, conventional pesticides, an unsprayed control plot, the local concoction of macerated neem leaves, and a combination of the fungal entomopathogen Beauveria bassiana Bb115 strain (with endophytic properties) and emulsifiable neem oil. The demonstration plots were also used as experimental fields to assess the presence of different cowpea pests as influenced by the various control approaches and their impact on yield. Results from the demonstration plots will be available later in the year.

3.1.5 Portable neem oil extraction system (CRI and SARI)

The CRI and SARI teams have and are continuing to explore the development of a low-cost portable neem oil extraction system for use at the village level. SARI has also explored the establishment of larger neem oil extractor with a Ghana-based entrepreneur.

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

The INRAB and IITA teams continue to work closely with Mywish Maredia (SO4.1) to perform survey studies to understand the potential for biopesticides in the pest control market in Benin. Data acquired during the survey last year were analyzed as scheduled. In Aplahoué et Klouékanmey in Southern Benin, a total of 120 cowpea producers were interviewed in four distinct villages. We particularly wanted to assess the farmer willingness to pay for alternative crop protection products as compared to chemical pesticides. The results show that some 5.8 percent of the farmers strongly favor the use of biopesticides, which can cost up to 250 CFA more per treatment, even if they do not significantly increase their monetary revenue, while 10 percent of the interviewed farmers strongly disapproved the same scenario. Some 50 percent of the interviewed farmers are ready to pay up to 300 CFA more per treatment with biopesticides if their yield is also increased.

Farmers being able to watch educational videos together is one of the goals of the project.

Farmers' general perception of biopesticides based on neem leaf extracts indicated that they perceive them to be less toxic and less expensive but difficult to use if they have to prepare them themselves. Their mode of action is slower and the yields are lower than when using synthetic pesticides. They also recognize that chemical pesticides are more efficient, faster in their action, and give a good yield but are well aware of their toxicity. They also mentioned that they would be willing to try new biopesticides that can be sold over the counter and that are more efficient than aqueous extracts.

IITA is continuing to work with SENS–Benin, a social enterprise that is extracting neem oil for sale. They purchase neem seeds from hundreds of local women, process the neem oil, and sell the oil regionally in Benin, targeting cowpea and vegetable farmers. IITA has been invited to participate at their meetings and workshops, and we are in discussions with them on how to diversify their biopesticide supply through their network of biopesticide retailers.

3.2 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, and an FFF program available for impact testing leading to educational packages for scaling. Potential pathways for deployment of educational videos have been explored, and we have been testing pathways to deploy videos. We have also been exploring pass-off of our educational materials to NGOs and government agencies for scaling. These have all occurred over the past 18 months. Due to the Scientific Animations Without Borders (SAWBO) program, we now have a significant amount of the required educational materials needed to educate farmers on techniques that they can use to reduce problems with insects. The project team is continuing to make more content and more language variants.

We have ICT training packages and interfaces in development and ready for release to make our materials easily available to outside groups. An ICT training session with 30 participants was held in Ghana in FY15, funded by the Chancellor's office at UIUC; two ICT training sessions took place online through Skype (100 participants); and the SAWBO team has conducted ICT training sessions in Burkina Faso and Ethiopia. More than 3000 credit card style USB card that hold SAWBO materials (Extension Systems in Your Wallet) have been created and distributed to educators, government officials, and NGOs globally over the past three years. Users can keep the USB drive in their wallet and share our educational materials.

The project has created and released Apps for cell phones that allow for easy distribution of the SAWBO animations. With the UIUC legal team, the privacy of App users is insured and all tracked data adheres to international standards and does not violate users' privacy. The Apple version of the App was finalized and released on iTunes at https://itunes.apple.com/us/app/id949627456. The Android version can be downloaded from Google Play at https://play.google.com/store/apps/details?id=edu.uiuc.sawbo&hl=en. An App database allows the project to track the number and location of people who download the videos. No other personal data is tracked.

This App allows people to choose the country, language, and educational topic they need. If available, they can download the needed animation onto their cell phone or tablets when they connect to WiFi. They can then take the cell phone or tablet to the target to show the video. These Apps make SAWBO educational content easily available to end users who can easily access and use these materials in educational programs. The Apps also provide us with basic information on their use and the content being chosen.

Interestingly, a significant amount of SAWBO materials are also being used by NGOs and government organizations outside our target countries. For example, animations funded by the ADM Institute for the Prevention of Postharvest loss resulted in animations for the Ethiopian Agricultural Transformation Agency (ATA). ATA purchased 640 tablet computers that were distributed to Extension agents across Ethiopia, with an estimated coverage of 168,000 Teff growers. Other SAWBO animations have been used in TV documentaries, at a Hausa-speaking TV station (AREWA24) based out of Kano in Nigeria, and the like. The animations are played between TV shows and the viewership can number in the millions.

In the project's four target counties, viewers over this past year have numbered in the thousands to tens of thousands, based on the use by host country scientists and NGOs that have used these tools. Additionally, an hermetic sealing animation was used in Mozambique in experiments to analyze learning gains from the animations, an instance of cross-collaboration between LIL programs, specifically, SO1.B1 and SO2.1.

This past year a manuscript was submitted on an experiment performed by the MSU–Maredia, INRAN, and the UIUC 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. For example, this past year INRAN held more than 16 FFF using this approach.

Objective 4. 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 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 an active role in undergraduate and graduate training programs.

4.2 Technician Training

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.

4.3 Cross-Institutional Capacity Building for Biocontrol Agents

Due to ongoing collaborative efforts, IITA, INERA, and INRAN are all well-positioned to rear and deploy biocontrol agents on a scale that we expect will significantly impact target pest populations in each of the project's host countries. Additionally, these organizations are in a position to test, train, and scale the neem-plus virus strategy for pest control. We have begun the process of transfer of this knowledge to our new partners in Ghana at CRI and SARI.

4.4 Systems to easily pass off 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) 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.

Major Achievements

1. Detailed studies on insect behavior, ecology, and biology to maximize the impact of biocontrol agents in the field.
2. Experimental analyses of field data have shown that the animated educational approach is as effective as the use of extension agent presentations. This strategy allows us to significantly scale our educational content.

Research Capacity Strengthening

CRI and INRAN both received capacity building awards. The CRI project's award revolved around the improvement of laboratory facilities, training of staff, and establishing the ability to rear pests and biocontrol agents/biopesticides. The INRAN project involved the establishment of a medium-scale facility for the production of a neem/MaviMNPV virus biopesticide.

Human Resource and Institution Capacity Development

Short-Term Training

IICT training sessions on the use of SAWBO materials for 75 men and 75 women from NGOs were held in Accra in spring 2015 by UIUC to benefit Ghana.

Regular trainings in Ghana, Niger, Burkina Faso, Benin, and Nigeria on the general use of SAWBO materials for approximately 2,600 men and 2,600 women from these countries was conducted by UIUC personnel throughout FY 2015. Farmers in these countries benefitted from the training.


Sifting the grain harvest.

Training sessions on the use of animations in Ghana, Niger, Burkina Faso, Benin, and Nigeria to benefit approximately 2,600 men and 2,600 women from these countries was conducted by UIUC personnel throughout FY 2015.

Training by Outside Groups in Collaboration with INRAN

1. Training was conducted for 31 extension agents who would benefit approximately 250 men and 250 women farmers in collaboration with a MercyCorps NGO working in Maradi.
2. Training was conducted on biopesticides in collaboration with the INRAN World bank project working in the Maradi and Zinder area. The training implemented 66 demonstration fields related to cowpea pest control. The estimated impact is at least 1,980 farmers.
3. Training for 120 farmers, including 40 women, on using biocontrol methods to control pests, was conducted with Sahel Bio and HEKS.EPER, a Swiss NGO, in September 2015.

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 women farmers.

Scholarly Accomplishments

Publications

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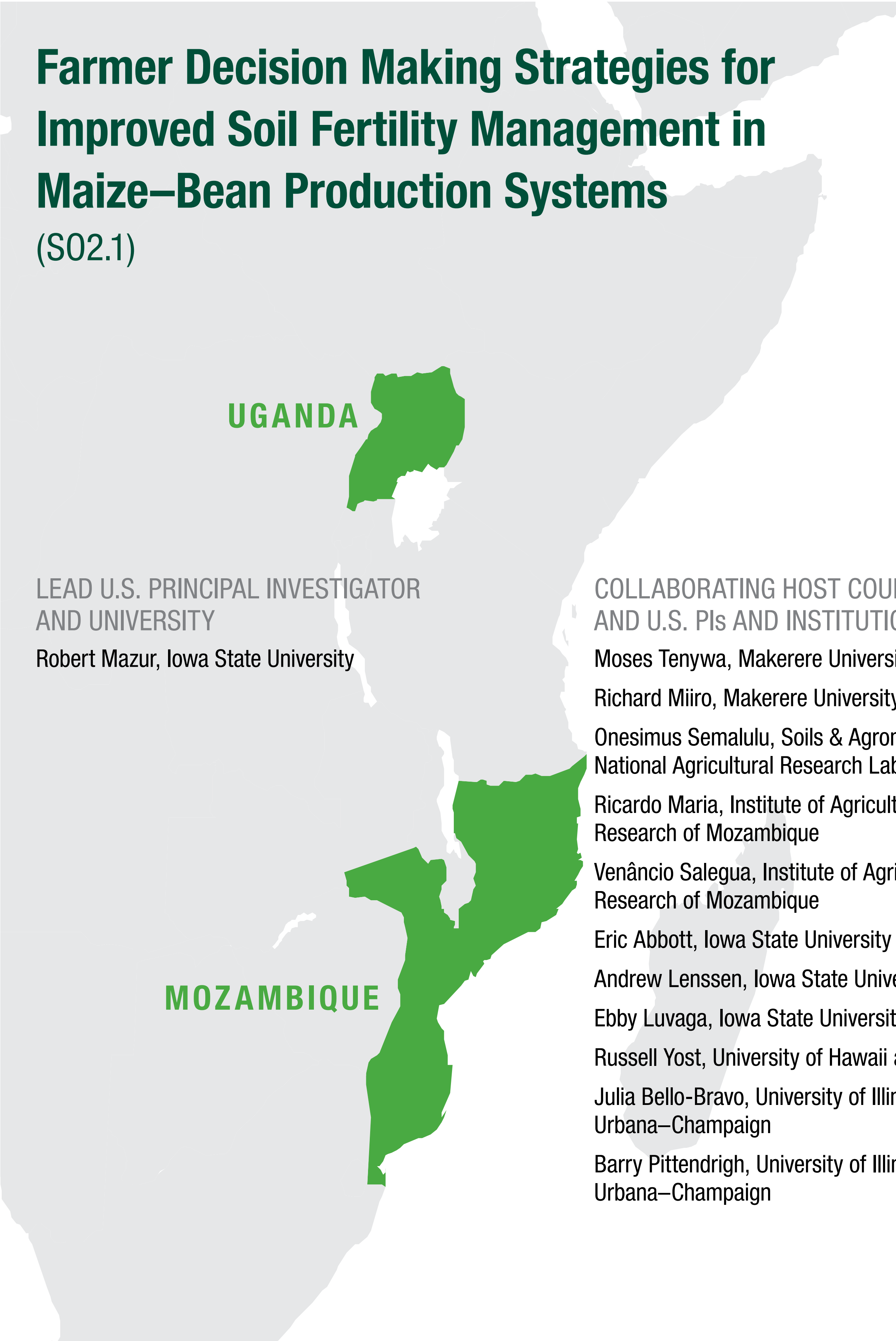
Toffa Mehinto, J., Atachi, P., Elegbede, M., Douro, K., Tamò, M. 2015. Efficacité comparée des insecticides de natures différentes dans la gestion des insectes ravageurs du niébé au Centre du Bénin. J. Appl. Biosci. 84:7695–7706.

Farmer Decision Making Strategies for Improved Soil Fertility Management in Maize–Bean Production Systems

(SO2.1)



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Abstract of Research Achievements and Impacts

The team analyzed physical and chemical properties of black, red, and stony soil samples from farmers' fields in key bean production districts in Uganda and Mozambique. Results guided nutrient omission studies that revealed the effects of N, P, K, Mg, Ca, S, and micronutrients on bean plant growth and development; these effects were complemented with lime requirement studies. Researcher-managed field trials conducted during two seasons used farmer-preferred and researcher-selected bean varieties. Treatments included seeding density, weeding frequency, P, Ca, Mg, Rhizobia, organic fertilizer, and seed and foliar fungicides. Analyses of farmers' resource endowments and social capital guide how we facilitate learning through on-farm experiments and farmer-selected field trials and demonstrations.

We are compiling and analyzing data on weekly market prices and marketing patterns. We developed an animated video, useful to farmers and for our research in Mozambique, comparing the efficacy of three training methods. We are assisting two emerging multistakeholder bean value chain innovation platforms in Masaka and Rakai districts that share interests, concerns, and strategies to address bean productivity and marketing constraints. They are participating in project research and training, and will be important in development, testing, disseminating, and using our diagnostic and decision support aids.

Project Problem Statement and Justification

Poor soil fertility is a major factor in low bean yields in Uganda and Mozambique, both important Feed the Future countries. Both have weak extension systems, limiting widespread access to information and materials that enable smallholder bean farmers to improve crop management practices, technologies, and yields. This research project is based on two premises:

1. Sustainable intensification of agriculture production requires improved soil fertility management in which legumes are an integral part of cropping systems.
2. Effectively addressing soil-related constraints involves enhancing smallholder farmers' capabilities in diagnosing and finding solutions to yield constraints as well as helping to remove barriers to increased access to various types of soil amendments.

Analyses of the soil's physical and chemical properties, combined with field trials, are revealing soil-specific effects of macro- and micronutrients on bean plant growth and development. Our documentation and analysis of farmers' cropping systems, practices, and technologies – and their resource endowments, is essential for the identification of strategies likely to be used to address key constraints.

Working with farmer groups and members of multistakeholder bean value chain innovation platforms enables us to engage producers in field experiments that test and demonstrate the impact of the most promising management practices and technologies for improved bean production and helps researchers learn about critical social, economic, and cultural factors that impact crop management decisions. Our research approach is generating practical results; strengthening social cohesion; collectively transforming farmers' knowledge, beliefs and actions; and stimulating interest among other farmers in learning from trials and demonstrations.

The project team is developing appropriate aids (methods and procedures) to enable smallholder farmers with varying levels of education to better diagnose soil-related production constraints and to make improved site-specific crop system management decisions that contribute to higher productivity of beans and associated crops and, over time, to improved soil fertility. We are assessing the effectiveness of innovative communication approaches and technologies to engage farmers with diverse characteristics and other key stakeholders in widespread dissemination and adoption of diagnostic and decision support aids.

Objectives

The project team is developing appropriate aids (methods and procedures) to enable smallholder farmers with varying levels of education to better diagnose soil-related production constraints and to make improved

1. Characterize Farmers' Practices, Problem Diagnoses, and Solutions.
2. Develop and Refine Models of Smallholder Bean Farmers' Decision Making.
3. Develop and Validate Appropriate Diagnostic and Decision Support Aids.
4. Develop and Assess Effectiveness of Innovative Approaches for Dissemination of Information and Decision Support Aids, Training, and Follow-up Technical Support.

Technical Research Progress

Objective 1: Characterize Farmers' Practices, Problem Diagnoses, and Solutions

Although farming system parameters in Uganda and Mozambique share some common features, there are significant differences that must be incorporated into the project's decision-making models. In Uganda, a median farm size is three acres, with 0.5 acres in beans planted in both growing seasons. In Mozambique, median farm size is much larger: 8.5 acres, with 1.7 planted acres in beans during the rainy season and 1.25 acres in the dry season. In both countries, 90 percent of farmers practice crop rotation in fields where beans are grown. Soil erosion is recognized by 70 percent of farmers in Uganda and 62 percent in Mozambique. Bean production constraints reflect different emphases in Uganda and Mozambique.

Bean crop experiment in Gurué

Following initial scientist-managed field experiments on farmers' fields with the most common soil types for bean production, the research team in Uganda actively engaged the wider community in all aspects of bean production and marketing. Multistakeholder bean Innovation Platforms (IPs) composed of farmers, input dealers, traders, credit institutions, and former extension agents are developing in Masaka and Rakai. IPs' goals include enhancing farmers' interactions, learning, information access, and decision making. Through them, our research team is sharing information, experiences and ideas on how to improve the bean value chain, engaging members in the project's on-farm research trials and demonstrations that foster collaborative learning, providing training and improving bean marketing practices. IP processes involve joint planning and activity coordination with other stakeholders in the districts.

Through the IPs, eight one-acre field trials have been established in the Masaka (n=3) and Rakai districts (n=5). Farmers, extension workers, students, and scientists have been involved in site selection and soils sampling for the field trials by soil type, cropping, and fertilizer use history and accessibility. Farmers freely provided the land and have been involved in setting up trials using an improved bean variety (NABE 17) with organic and inorganic fertilizers, management (weeding, spraying), and evaluation (field observations) of crop development at different stages. These trials serve as learning sites for approximately 30 neighboring farmers at each site. Inputs for each learning site including bean seed, poultry manure, inorganic fertilizers, and extension support have been collectively financed and supported by members of the IP, including three nonprofit organizations and the research project team.

Farmers in Mepuaguía identified three types of soils based on their color and the crop typically planted on that soil that is likely to succeed:

1. *Ekotchokwa* is red soil at the summit.
2. *Epupu* is black soil at the summit.
3. *N'tchokwa* is black soil in the basin.

Farmers reported that when beans are planted on the red summit soils, there is almost no crop grain yield. This represents an opportunity for the project to illustrate that with appropriate crop and soil management beans can be grown on such positions. In the majority of our recent cropping experiments in Gurué, there is a near ubiquitous response of beans to the addition of nitrogenous fertilizers.

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

Farmers are aware of the different types of soils, their physical properties, and their productivity/suitability for different uses. They also know the rainfall patterns in their locations but are less precisely aware of soil nutrients and pest and disease control regimes. They learn from fellow farmers, extension workers, and researchers. Once a given practice is viewed as beneficial and affordable, an innovation's adoption or adaptation depends on its compatibility with their landscape and farming system, its relative advantage (local availability, benefit-cost analysis, multifunctionality), their ability to experiment with the practice, and their household resource endowment. Farmers generally understand the advantages of using good agronomic practices such as timely planting, line planting, fertilizer application, and pest and disease control regimes, but they are concerned with the costs and labor involved in using a given practice.

IP members in Rakai have accessed improved bean seed from CEDO (Community Enterprises Development Organisation), paying it back after harvest. CEDO has offered IP member farmers the opportunity to grow bean seed on a contract arrangement to expand the local supply of quality seed.

Training on triple bagging to preserve postharvest crops in Rakai

In Uganda and Mozambique, the project team tracked bean prices in local and regional markets weekly. We are analyzing baseline household survey data to understand the demographics, production assets and practices, marketing practices, etc. of farmers who received the highest prices for their marketed beans to identify strategies that other farmers might adopt or develop. Most farmers lack reliable storage capability and therefore sell their beans soon after harvest. Farmers greatly appreciated the training provided by project researchers in mid-2015 on anaerobic storage (triple bagging and jerry cans) which can allow them to safely store their beans as seed, grain for consumption, and marketing with minimal damage from pests.

District Agricultural officers and traders cited major challenges and constraints for farmers in production, quality control, and marketing of beans. Farmers benefitted from training in seed quality and the importance of single variety beans as well as in record keeping (production costs and sales). Increasing integration of capital-intensive inputs such as fertilizers, foliar spays, pesticides, and fungicides into farmers cropping systems required tracking the various costs and determining returns to investment. Such an approach will help us in developing recommendations that cater for heterogeneity in smallholders' resource endowments, particularly land size, livestock ownership, and income. Further, in the absence of a vibrant extension service system, men do not consistently share information with women, who are thus at risk of being left behind in efforts to improve agricultural practices.

Objective 3: Develop and Validate Appropriate Diagnostic and Decision Support Aids

Uganda. The Nutrient Omission study conducted in Uganda found the main effects of soil and nutrient omission treatment were significant for aboveground biomass accumulation of common beans, but the interaction of soil × nutrient omission was not significant. Plants growing in Haplic Luvisol accumulated significantly higher biomass than plants grown in other soil types (figure 1). Plants grown in Haplic Luvisol accumulated 27.7 percent and 33.6 percent greater aboveground biomass than those grown in Leptosol (and Skeletic Luvisol, respectively).

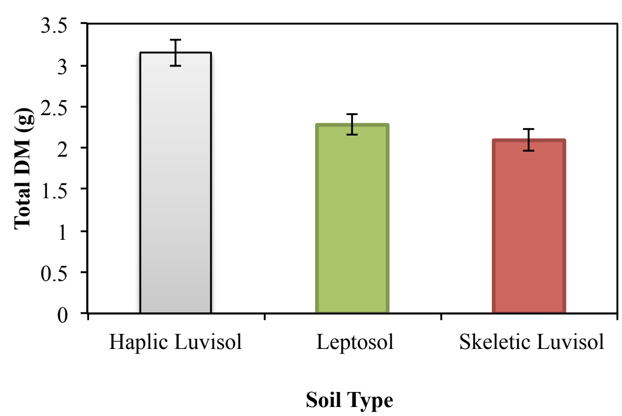

Figure 1. Mean aboveground biomass (g plant-1) for common bean grown on three soils.

Across soil types, the all-nutrients supplied treatment had greater aboveground biomass than the phosphorus omission and the unamended control (figure 2). However, the all-nutrients supplied treatment was not different from all other omission treatments, indicating that phosphorus availability is a primary factor limiting common bean growth in predominant soils in Masaka. Beans grown in phosphorus omission treatment accumulated 39.6 percent lower above ground biomass than those in the complete treatment. Beans grown in the control treatment accumulated 41.5 percent less aboveground biomass than the all nutrients supplied treatment.

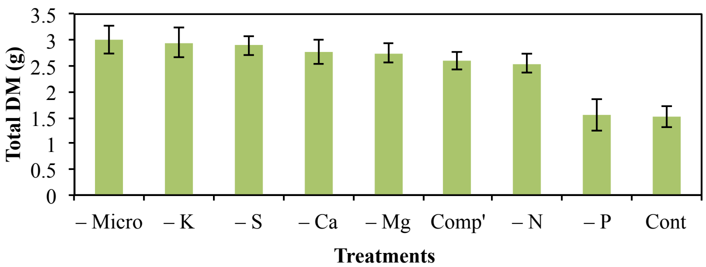

Figure 2. Mean aboveground biomass for nine fertility treatments in a nutrient omission study.

The Nutrient Omission study conducted in Uganda found that the main effects of soil and nutrient omission were significant but the interaction of soil × nutrient omission treatment was not significant.

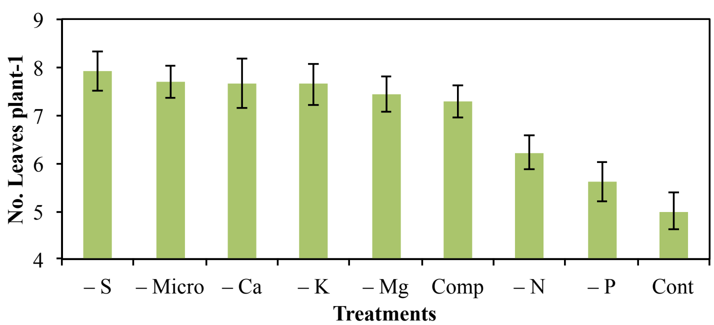

Figure 3. Mean number of leaves per bean plant for nine nutrient treatments over three soils.

Our results demonstrate that the Haplic Luvisol has inherently greater fertility than the other two soils. Additionally, improved P and N availability likely will increase bean growth, development, and yield in the predominant soils in Masaka, Uganda.

A field study was conducted in the Masaka District to determine whether an improved bean management system could significantly increase bean yield and profitability. The main plot factor was three management systems; the subplot factor was four bean varieties. Management systems (farmer management system, low-input, and high-input) differed for seed treatment (no vs. yes), seeding density (10 vs. 20 seed m^{-2}), plant configuration (broadcast vs. rows), liming (no vs. yes), fertilizer applications (P, K, Ca, Mg, Zn, and S), rhizobium inoculation (no vs. yes), pesticide applications (no vs. yes), and frequency and timing of weeding. Subplots were four popular varieties, the older varieties K132 and NABE 4, and two newer varieties with improved resistance to common diseases, NABE 14 and NABE 15. The study was conducted on two soil types. The black Liddugavu soil type was described as a Phaeozem using the FAO-UNESCO Soil Legend and as a Mollisols using USDA Soil Taxonomy. The red Limyufumyufu soil type was described as a Ferrosol using the FAO-UNESCO Soil Legend and as a Eutrudox using USDA Soil Taxonomy. Both soils had sandy clay loam texture. Specific fertilizer rates differed between sites due to fertility differences between soils. Farmers avoid planting beans on red soil if black soil is available due to the differences in fertility (table 1).

Property	FMS	Low-input	High-input
	Black Liddugavu		
pH	6.6	6.5	6.5
P (mg kg^{-1})	27	32	27
K (mg kg^{-1})	89	124	101
Ca (mg kg^{-1})	1898	2058	1910
OM (g kg^{-1})	39	34	36
Base Saturation	89	88	88
	Red Limyufumyufu		
pH	5.2[b]	7.0[a]	7.1[a]
P (mg kg^{-1})	4[b]	15[a]	19[a]
K (mg kg^{-1})	49[b]	79[a]	87[a]
Ca (mg kg^{-1})	785[b]	3138[a]	3603[a]
OM (g kg^{-1})	38	37	39
Base Saturation	54[b]	94[a]	95[a]

Table 1. Postharvest soil pH, available P, K, and Ca, organic matter, and base saturation from three common bean management systems in two soils. Masaka District, Uganda, 2014. Means within property and soil type followed by different letters are significantly different by protected LSD ($P<0.05$).

In 2014, management system and the management system × variety interaction were significant for bean yield on both black (table 2) and red soil (figure 5). On black soil in the low-input management system, NABE 4 (1475 kg ha^{-1}) produced greater yield than did NABE15 (1175 kg ha^{-1}) and K132 (1000 kg ha^{-1}) (figure 6). Additionally, NABE 14 (1351 kg ha^{-1}) produced significantly greater yield than K132, the lowest yielding variety. Varieties did not differ for yield in the high-input management system on black soil. Averaged across varieties, beans grown on black soil under the high-input management system had seed yield of 1808 kg ha^{-1}, 98 percent greater than the farmer management system (FMS) which had yield of 912 kg ha^{-1}. The low-input and high-input management systems did not significantly differ in yield on black soil, producing 1238 kg ha^{-1} and 1808 kg ha^{-1}, respectively.

Treatment	Plant stand R9 (# m^{-2})	Height (cm)	Pods (# m^{-2})	Seed (# pod^{-1})	Seed (mg $seed^{-1}$)	Biomass (g $plant^{-1}$)	Grain (kg ha^{-1})	PHI
Management System [b]								
CFS	8 b	29	40 b	2.9	425	21	593 b	76
IFS	17 a	31	67 ab	2.8	387	16	818 b	77
HIS	17 a	34	92 a	2.9	437	18	1275 a	75
Variety								
NABE 14	15 a	36 a	90 a	3.2	417 ab	22 a	1212 a	73 b
NABE 15	13 b	23 c	52 b	2.6	378 a	18 ab	668 c	81 a
K132	14 a	34 ab	62 b	2.8	431 b	17 b	803 bc	74 ab
NABE 4	14 a	32 b	63 b	2.9	439 b	16 b	899 b	76 a
Rainy season [c]								
2014L	13 b	38 a	91 a	3.3	445 a	27 a	1318 a	76
2015S	15 a	25 b	42 b	2.5	388 b	9 b	473 b	76
Significance	P > F							
System (S)	***	NS	*	NS	NS	NS	*	NS
Variety (V)	***	***	***	***	*	*	***	*
S × V	**	NS	NS	NS	NS	NS	NS	NS
Rainy season (R)	***	***	***	***	***	***	***	NS
S × R	NS	**	*	NS	NS	**	**	NS
V × R	**	**	***	***	NS	***	***	NS
S × V × R	NS	NS	*	NS	NS	NS	*	NS

Table 2. Yield, yield components, and pod harvest index (PHI) for bean in three management systems and four varieties for two rainy seasons on Black Soil.[a]

[a] Means within treatment and column followed by the same letter, or no letter, are not different at *P*=0.05.

[b] CFS, Conventional Farmer System; IFS, Improved Farmer System; HIS, High Input System

[c] Rainy season: 2014L, long rainy season; 2015S, short rainy season.

NABE 4 frequently produced significantly greater yields than the other bean varieties under the improved management systems. The high-input management system produced significantly greater yields than the FMS on black soil. Beans grown on red soil under either of the two improved management systems produced significantly greater yields than the FMS. After one rainy season of production, beans grown on black soil obtained the greatest profits by utilizing either of the two improved bean management systems compared to the FMS (results not presented). Conversely, beans grown on the red soils obtained the greatest profits under the FMS. On the red soil, beans grown on the improved management systems registered a net loss due to the need for greater amounts of expensive agricultural inputs to improve productivity.

Field studies to determine optimum combinations of organic and inorganic fertilizers for beans grown on three contrasting soils—black, red, and gravelly—have been ongoing in Masaka since August 2014. Results to date over two seasons indicate a significant grain yield improvement following combined application of organic and inorganic fertilizers compared to either organic or inorganic application alone.

For 2015A, the main effects of soil type, manure, the two-way interaction of soil × manure, and four-way interaction of soil type × manure rate × N rate × P rate were significant for bean yield.

Results from the field experiments show that combined application of organic and inorganic fertilizers is more beneficial than either organic or inorganic fertilizer applied separately. The fertilizer must be applied at planting. Timely planting is crucial. In addition regular monitoring of pests on weekly basis is essential. Timely management activities such as weed control are needed for the recommended fertilizer rates to be effective.

Mozambique – Soil acidity is a key limiting factor for crop production in highly weathered Oxisols of Gurué. Increasing crop yield with fertilizer use requires soil amelioration and

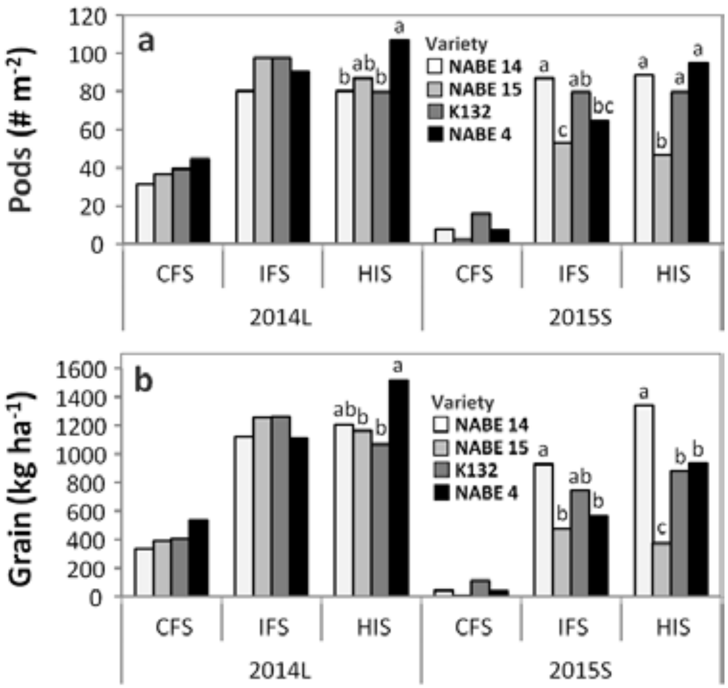

Figure 5. The interaction of management system × variety × rainy season for (a) pod density and (b) grain yield of bean. Management systems include conventional farmer system (CFS), improved farmer system (IFS), and high input system (HIS) on Limyufumyufu (red) soil.

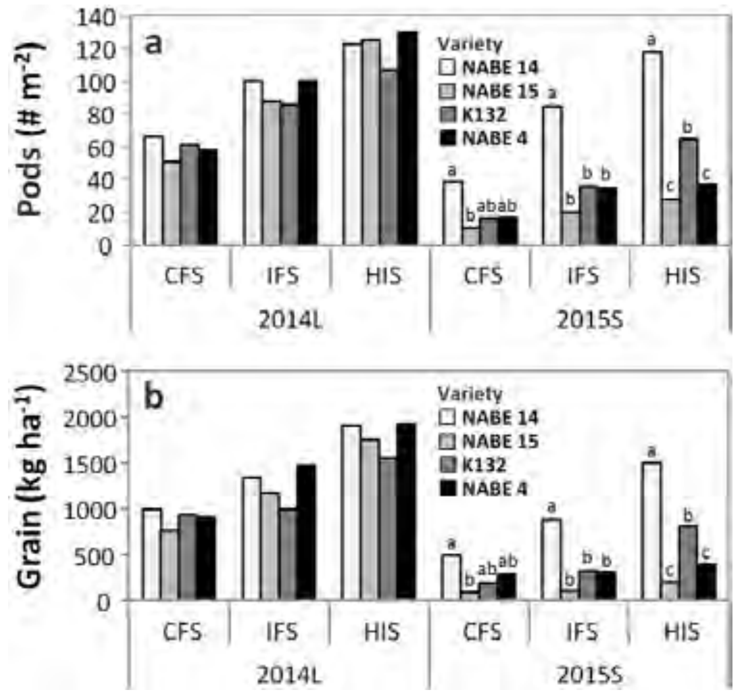

Figure 6. Interaction of management system × variety × rainy season for (a) pod density and (b) grain yield of bean. Management systems include conventional farmer system (CFS), improved farmer system (IFS), and high input system (HIS) on Liddugavu (black) soil.

neutralization of potential acidity and hence improving nutrient availability. Soil samples were collected from paddy-rice production areas where beans are grown during the dry season following the rice harvest. Samples were analyzed for pH and color in the laboratory of Instituto Medio Agropecúario de Gurué. The pH ranged from acidic to very strongly acidic. Soil color, an indicator of soil quality, was measured with Munsell Soil-color charts in wet and dry samples. The color of wet samples color ranged from Dark Reddish Brown to Black. When dry, the dominant colors are Brown, Dark Brown, and Dark Yellow Brown.

Based on preliminary soil analyses, an experiment was conducted to assess the effect of limestone in combination with fertilizer and inoculant on common bean yield using a randomized complete block design in a strip-plot treatment structure with fertilizer, lime or a combination in the main plot and inoculated versus uninoculated seed in strip-plots. Agronomic and phenological data were collected and are being analyzed.

Soil fertility is a limiting factor for bean yield in Gurué, exacerbated by a cyclic burning of rice straw after tilling the soil. It is generally known that P and K are the most limiting nutrients for bean production. To diagnose other limiting plant nutrients, an additional experiment was conducted on-farm in a paddy rice production system. A randomized complete block design with three replications was used in a split plot treatment structure. In one experiment, fertilizer applications were assigned to the main plot and two promising improved bean varieties were assigned to a subplot. An additional experiment with a local preferred bean variety was used with same experimental design. Tested plant nutrients were control (no fertilizer added), PK, NK, NP, NPK, NPKS, NPKS+Zn + ZnB, and 7NPKS+ ZnB. Nutrients used were Urea, Diammonium Phosphate (DAP), SOP, triple superphosphate (TSP), Muriate of Potash (MOP), Zinc oxide, and Borax at 30 kg N ha^{-1}, 34.5 kg P2O5 ha^{-1}, 24.0 kg K2O ha^{-1}, 2.5 kg ZnO ha^{-1}, 0.5 kg B ha^{-1}. Agronomic and phenological data, including the use of photographs of plant canopies at different developmental stages, were collected and are being analyzed for diagnosing limiting plant nutrients and performing comparisons among treatments.

Soil fertility is declining due to continuous cultivation without nutrient replenishment through fertilization. To understand farmers' perceptions about differences in crop performance for experiments and treatments, a two-day field day was organized in Mepuagíua. The aims of the field day were to create awareness among farmers about soil fertility problems through differences in crop performance; to compare and contrast crop responses in different soils; to exchange ideas and views among farmers, researchers, agricultural college faculty members and students, and local community leaders; and to identify research issues for future study. During the field day, it was evident that there was a lack of understanding among farmers about basic agroecosystem of bean production, including implications of plant density for pest management and crop productivity and cause and effect of different treatments on crop performance. Farmers considered the event a learning opportunity and recommended this kind of interaction in future project activities.

Objective 4: Develop and Assess Effectiveness of Innovative Approaches for Dissemination of Information and Decision Support Aids, Training, and Follow-up Technical Support

Farmers benefit from having a variety of means to access information to learn about ways to improve bean production, storage, and marketing. The project is exploring the efficacy of video, particularly animated videos. In advance of having content based on project field results that will serve as soil fertility diagnostic and decision support aids, it is important to begin to understand communication patterns and dynamics in the study communities in both countries. For this, we enhanced training materials for a technology that was promoted in a previous project—anaerobic storage using triple bags and sealed plastic jerry cans. Prototype messages and training approaches were developed for both Uganda and Mozambique. These included two main approaches: 1) expert extension hands-on presentations in which an agent demonstrated postharvest bean storage (using triple bagging and jerry can storage in Uganda, and jerry can storage in Mozambique); and 2) a video of each step of the postharvest process and animations showing the steps of the process. In all cases, farmers viewing the training were asked to carry out the tasks in a demonstration following the training.

Extension training, video shot locally in the local language, and an animation developed by SAWBO were tested. Animations were created, reviewed by experts, and translated into the local language. In Uganda, groups of key farmers from both Masaka and Rakai were brought together for the training. Farmers were asked to evaluate all forms of training, and to indicate which they preferred. In Mozambique, a field experiment was conducted with 314 randomly selected farmers from ten communities out of two different Administrative Posts in Gurué (Tetete and Mepuagiua) to compare the effectiveness of the extension-only approach and an animation approach delivered via smartphones. The animation, translated into Lomwe (see https://www.youtube.com/watch?v=ACIyKKEkpgc to view the English language version), shows the jerry can postharvest storage technique for preserving beans.

Farmers received one of three treatments: (1) extension only, (2) animation only, (3) both—the order was varied. Following all of the treatments, farmers were asked to carry out the task of filling the jerry cans with beans for storage. Already, some men and women Innovation Platform farmers in Uganda have run their own experiments and trained other farmers in airtight storage, particularly using the jerry can method. Those passing on the knowledge to others particularly in Rakai are mainly women. In Gurué, the administrator of the district and the local agriculture director met and officially authorized the research team to proceed with testing the prototype and shared their enthusiasm and willingness to see positive results being implemented beyond randomly selected communities.

The baseline household survey documented the importance of these fellow farmers in adoption of many soil fertility and bean practices in the country. Video and animations were both well-received by these farmers, so they can be included in future communication approaches. In Mozambique, early results show that the smartphone animated videos were at least as effective as the extension-only approach, and that farmers learned significantly about specific steps to follow by viewing either approach. Because of the lack of extension agents in Gurué, animations delivered by smartphones will be an important part of future communication efforts.

Major Achievements

- Broadened and deepened understanding of farmers' resource endowments and social capital; this understanding guides how we generate interest and cooperation, and facilitate learning through on-farm experiments and farmer-selected field trials and demonstrations, and will promote adoption and adaptation of improved management practices and technologies.
- Training in anaerobic storage methods (triple bags and jerry cans), using extension personnel and a newly developed animated video, met an important farmer need.

Research Capacity Strengthening

The project team benefitted from four Institutional Capacity Strengthening grants. The first focused on combining indigenous and scientific knowledge of soils.

The second enabled the Institute of Agriculture Research of Mozambique to record, analyze, and interpret GIS associated data with biophysical, economic, and social data.

The third involved training workshop for IIAM and Instituto Medio Agropecúario de Gurué, University of Zambézia researchers in survey techniques to learn how farmers identify local indigenous soil types and then use that information in their selection of cropping systems and crop and soil management as well as training on spatial data management.

The fourth supported the training of scientists, technicians, students, and district staff in GIS and geospatial skills for distinguishing toposequencing, chronosequencing, and lithosequncing of soil catena in Uganda in September 2015. Through field and lab-based activities, trainees acquired practical skills and detailed understanding of soil variability along selected landscapes of the Buganda catena using characteristics identified locally by farmers and related it to modern scientific approaches. Trainees also developed practical skills to enhance farmer decision making for soil fertility management through the combined use of indigenous and modern scientific soil classification.

During June to August 2015, Mr. Rocha provided supervision and training on soil sampling and crop harvesting techniques in Gurué, Mozambique. Eng. Ricardo Maria conducted field demonstrations of a portable soil pH test kit to EMAPEG students. Three project graduate students at Makerere benefitted from training in designing and conducting gender sensitive research. Dr. Miiro participated in LIL-sponsored training in Lusaka, Zambia, on the impact assessment of projects.

Human Resource and Institutional Capacity Development

Short-Term Training

Training on GIS and geospatial skills through computer and field observations for 10 women and 24 men was conducted through Iowa State and Makerere Universities in Mocuba, Mozambique, in June 2015. The training helped attendees learn how to manage indigenous soil types through spatial data management in soil research.

Innovation Platform
Using participatory methods, training on innovation platform strengthening for 58 women and 79 men was conducted through Iowa State University, Makerere University, UICC, and National Agricultural Research Laboratories in Masaka and Rakai, Uganda.

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, 64 women have benefited (of 172 trainees) and one woman is benefitting from long-term training. Extension research in Mozambique involved 140 women (and 174 men).

Scholarly Accomplishments

Goettsch, L. **& A. Lenssen**. 2014–2015. U.S. Borlaug Fellows in Global Food Security graduate research grant. Practical methods to alleviate constraints to common bean (Phaseolus vulgaris L.) production in Masaka, Uganda.

Mazur, R., N. Bwambale **& V. Salegua.** 2015. Land Rights and Integrated Soil Fertility Management in Uganda & Mozambique. Paper presented at LANDac Conference 2015–Land Governance for Equitable and Sustainable Development. Utrecht, Netherlands.


PLYWOOD

Enhancing Value-Chain Performance through Improved Understanding of Consumer Behavior and Decision Making

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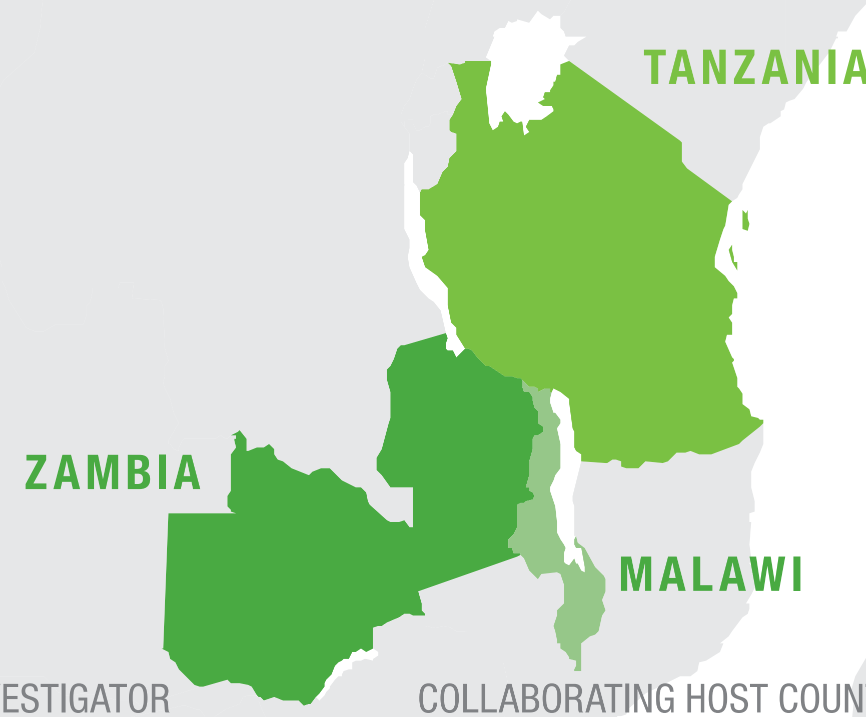

LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

Vincent Amanor-Boadu, Kansas State University

COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

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Kara Ross, Kansas State University

Abstract of Research Achievements and Impacts

During FY 2015, the research team conducted electronic discrete choice experiments in each of the three target countries: Zambia, Malawi, and Tanzania. More than 2,300 surveys were completed. The lead U.S. PI facilitated two workshops on entrepreneurial activities and strategic alliances in the food and agribusiness industries in each of the three focus countries. In total, 157 people attended the strategic alliances workshops and 131 attended the three entrepreneurial workshops.

During each of the country visits, the U.S. PIs and HC PIs met with key industry partners to establish a partnership and start planning an industry-wide conference in each of the focus countries for FY 2016.

The first round of recruited students has either graduated or is close to graduation; they have completed reports on each country's situational analysis. Key findings from these students' reports indicate that, on average, bean shares of total food expenditure were about 3.5 percent, with individuals in a high income bracket allocating a smaller share of their food expenditure to beans. Interestingly, urban consumers allocated a higher proportion of their food expenditure to beans than rural consumers. To date, almost 20 students have been recruited to work on this project for their degree training requirements.

Project Problem Statement and Justification

Grain legumes are not traditional staples in Zambia, Malawi, and Tanzania, despite having significant nutritional benefits. Thus, increased consumption to support smallholder producers' economic well-being must be based on a clear appreciation of how consumer characteristics and food attribute-level combinations shape consumers' decisions and choices. The fundamental problem of this project, therefore, is to develop new understanding of the forces and factors shaping and influencing consumers' food choice decisions in eastern and southern Africa and using this understanding to facilitate improvements in legume value chains.

The project has three integrated dimensions. First, it develops an empirical foundation for understanding the factors and the extent that these factors influence food choices. This dimension is the first empirical evaluation of the complex factors influencing consumer choice of grain legumes in eastern and southern Africa. The research then employs the results of these factors and the extent to which they shape consumer choices to engage industry stakeholders and public institutions in a search for value creation and value expansion opportunities and solutions to challenges preventing value chain effectiveness.

The third dimension involves using the information collected on industry capacity gaps to carefully develop and deliver training and outreach programs aimed at enhancing strategy development, management, and decision-making. In the end, the project provides innovative and unique pathways that bring smallholder producers and other stakeholders into specific value chain alliances to help smallholder producers improve their economic well-being.

The geographic scope of the research covers Zambia, Malawi, and Tanzania, all Feed the Future focus countries. These countries represent the changes occurring in eastern and southern Africa—increasing urbanization; economic growth and increasing but unequally distributed incomes; and changing demographics, including in agricultural production. This research will provide insights into how and where these changes are affecting legume consumption and how these markets can overcome domestic consumption barriers to build stronger value chains to seize new markets.

Objectives

1. Identify and analyze the principal factors shaping bean/cowpea consumption and their relative positions in consumers' food rankings in the selected countries.
2. Conduct situation analyses for bean/cowpea production and marketing/distribution systems with a view to identifying the nature and extent of the gaps in their value chains.
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.

Technical Research Progress

Objective 1: Identify and analyze the principal factors shaping bean/cowpea consumption and their relative positions in consumers' food rankings in the selected countries.

Approaches and Methods

The project team employed a discrete choice experiment method to complete objective one. Additionally, statistical methods were employed to rank beans/cowpeas in consumers' food baskets in Zambia.

Two groups of variables are included in the experiment. The first group of variables includes product attributes (availability, accessibility, perceived nutritional characteristics [fiber, protein, etc.], preparation time and options, color, storage characteristics, taste, size, and price. The second group includes consumer characteristics (frequency of consumption, quantities consumed, and expenditure shares) and preference influencers (cultural and biologic-ecologic variables). The theoretical strength of a discrete choice approach is that the choice set always includes at least one feasible alternative.

Because there is a random component in random utility theory, preferences are inherently stochastic. Therefore, the foregoing analytical approach facilitates only the prediction of the probability that an individual, *I*, will choose beans/cowpeas. The approach, thus, leads to the development of a family of probabilistic discreet choice models that describe how probabilities respond to changes in the choice options (attributes) and/or the covariates representing differences in individual consumers. Therefore, the probability (ρ) that individual *i* chooses option *j* from her or his set of competing options, C_i, equals the probability that systematic (*V*) and random (ε) components of option *j* are larger than the systematic and random components of all other options competing with *j*. That is:

$$\rho(j|C_i) = \rho[(V_{ji} + \varepsilon_{ji}) > \max(V_{ki} + \varepsilon_{ki})] \quad \forall\, j,k \in \{C_i\}$$

The systematic components include attributes that explain differences in the choice alternatives and covariates that explain differences across individuals. The random components, a fundamental aspect of the model's authenticity, capture all the unidentified factors that influence choices. Together, they define the latent utility, u_{ji} individuals associate with each alternative, as follows:

$$u_{ji} = V_{ji} + \varepsilon_{ji}$$

> ***. . . increased consumption [of grain legumes] to support smallholder producers' economic well-being must be based on a clear appreciation of how consumer characteristics and food attribute-level combinations shape consumers' decisions and choices.***

Results, Achievements and Outputs of Research

- U.S. PIs facilitated a two-day training session for enumerators in each of the three focus countries on the survey in spring 2015. Specifically, the training explained the discrete choice experimental approach and how to use computer tablets. Although the selected enumerators were experienced with the traditional survey approach, it was important that they were introduced to and became familiar with the discrete choice method since they were to administer the survey. By gaining an understanding of how the discrete choice experiment was designed, the enumerators could accurately administer the survey to assure valid and unbiased responses. It was also important that the enumerators practice using the tablets to gain familiarity with the computer-assisted personal interview. During the enumerator training, the host country PI facilitated the translation of the survey into the local languages to ensure that the survey questions were clear and logical, and the language and context used for the questions appropriate to elicit unbiased and informative responses.

- A pretest involving the enumerators was conducted as part of the training in each of the three focus countries. Feedback and suggestions for improving the survey were received and incorporated.

- All the surveys were conducted in the focus countries over a period of four to six days in spring 2015. Seven hundred and thirteen surveys were collected in Malawi, 766 in Tanzania, and 884 in Zambia.
- Survey data have been collated, organized, and cleaned for all three surveys.
- Background research and literature reviews have been conducted to provide support for the research methods and survey design and to develop the framework for the research reports and policy briefs that will be generated from the findings of these discrete choice experiments. The recruited students in Malawi, Tanzania, and Zambia are working on the following research projects, respectively:
    - o Consumer Choice and Preferences for Beans in Lilongwe: A Discrete Choice Modeling approach,
    - o Bean Production and Marketing in Tanzania, and
    - o Consumer Preferences for Beans in Zambia.
- All three studies investigated consumer preferences for different food types and identified the socioeconomic and demographic characteristics that influence the consumption of beans.

Objective 2: Conduct situation analyses for bean/cowpea production and marketing/distribution systems with a view to identifying the nature and extent of the gaps in their value chains.

Approaches and Methods

Objective 2 employed econometric analyses on secondary data collected by various institutions in the project's host countries to develop a deeper appreciation of the grain legume production environment, including the gender issues underscoring the environment. The World Bank's nationally representative *Living Standards Measurement Survey – Integrated Survey on Agriculture (LSMS-ISA)* Data for Malawi and Tanzania and the *Food Security Research Project* (FSRP) dataset for Zambia were used to conduct situation analyses. Primary data were also collected and used in the situational analyses.

Results, Achievements and Outputs of Research

- Recruited students in Zambia worked on completing the reports on the situational analysis of production and consumption of common beans in Zambia. Drafts of these reports were completed December 2015.
- Newly recruited students in Malawi and Tanzania are expected to expand on the completed research studies conducted by last year's students.
- These reports and research studies are expected to be a part of the students' MS theses.

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.

Approaches and Methods

Research partners in Malawi, Tanzania, and Zambia recruited MS students for their projects. Each host country PI is planning to have two MS students recruited by the beginning of the 2015–2016 academic session, in addition to the current MS students recruited the previous year. Concurrently, active recruitment for qualified participants from the food and agribusiness communities in Zambia, Malawi, and Tanzania to join the Masters of Agribusiness program at Kansas State University began. The research partners were primarily responsible for searching for qualified candidates and working with the U.S. PIs to facilitate it.

Results, Achievements and Outputs of Research

- Each of the focus countries has recruited at least one man and one woman student. Zambia has recruited a number of upper-level undergraduate students to focus on this legume research project for their Honors projects.
- Zambia has recruited another student for the Master of Agribusiness program.
- The Tanzanian PI and his department recruited two students for the Master of Agribusiness program and will be selecting one student to sponsor in Spring 2016.
- The Malawian PI and his department recruited four students for the Master of Agribusiness program and have selected one student to sponsor for Spring 2016 enrollment.
- The Malawian PI and his department have partnered with the Department of Agribusiness to train agro-dealers, including members of the Association of Agribusiness Women.

- o As part of the program, training is expected to begin in Spring 2016. The training sessions will be based on the results of the *Needs Assessment* questionnaire that was developed; translating the questionnaire into local languages is in process. The questionnaire is expected to be administered in the first quarter of FY2016.
- o The U.S. PIs and other host country PIs are providing guidance and support toward this training initiative, and the research team plans on developing similar needs assessment and training sessions in Tanzania and Zambia.

Major Achievements

One achievement was the completion of the discrete choice experiment in each of the focus countries. A second was the facilitation of industry-wide workshops on entrepreneurial activities and strategic alliances, which created an opportunity for the PIs to meet key industry players and develop partnerships for future activities. These partnerships are crucial to the success of future activities because these partners have a wealth of knowledge and deep networks in the bean industry. They will play an important role in analyzing the *Needs Assessment* questionnaire results and determining which knowledge gaps and skills training will be addressed in each country. These partners will also provide valuable support in disseminating information to all bean producers, industry players, and interested parties by helping with translating information into local languages, organizing and promoting training sessions, and developing distribution channels to share information with those unable to attend the training sessions and other future activities.

Research Capacity Strengthening

Training the Enumerators

Kansas State University PIs led *Training the Enumerators*, which was also part of the research team's training on discrete choice experiments. The host country PIs helped facilitate the enumerator training in Malawi and Tanzania. Since the enumerator training in Zambia occurred last fiscal year, a short training session for the Zambian enumerators was provided by the Kansas State University PIs and the host country PIs to refamiliarize them with the discrete choice experiment section of the survey.

Human Resource and Institution Capacity Development

Short-term Training

A workshop on *Enhancing Performance through Strategic Alliances* was conducted by KSU PIs for 26 women and 43 men on January 29, 2015, to benefit Malawi.

A workshop on *Entrepreneurial Action in Food and Agribusiness Companies* was conducted by KSU PIs for 18 women and 25 men on January 30, 2015, to benefit Malawi.

A workshop on *Enhancing Performance through Strategic Alliances* was conducted by KSU for 10 women and 32 men on March 3, 2015, in Dar Es Salaam to benefit Tanzania.

A workshop on *Entrepreneurial Action in Food and Agribusiness Companies* was conducted by KSU for 10 women and 32 men on March 4, 2015, in Dar Es Salaam to benefit Tanzania.

A workshop on *Strategic Alliances and Entrepreneurial Action in Agribusiness* was conducted by KSU for 22 women and 24 men on March 31, 2015, in Lusaka, to benefit Zambia.

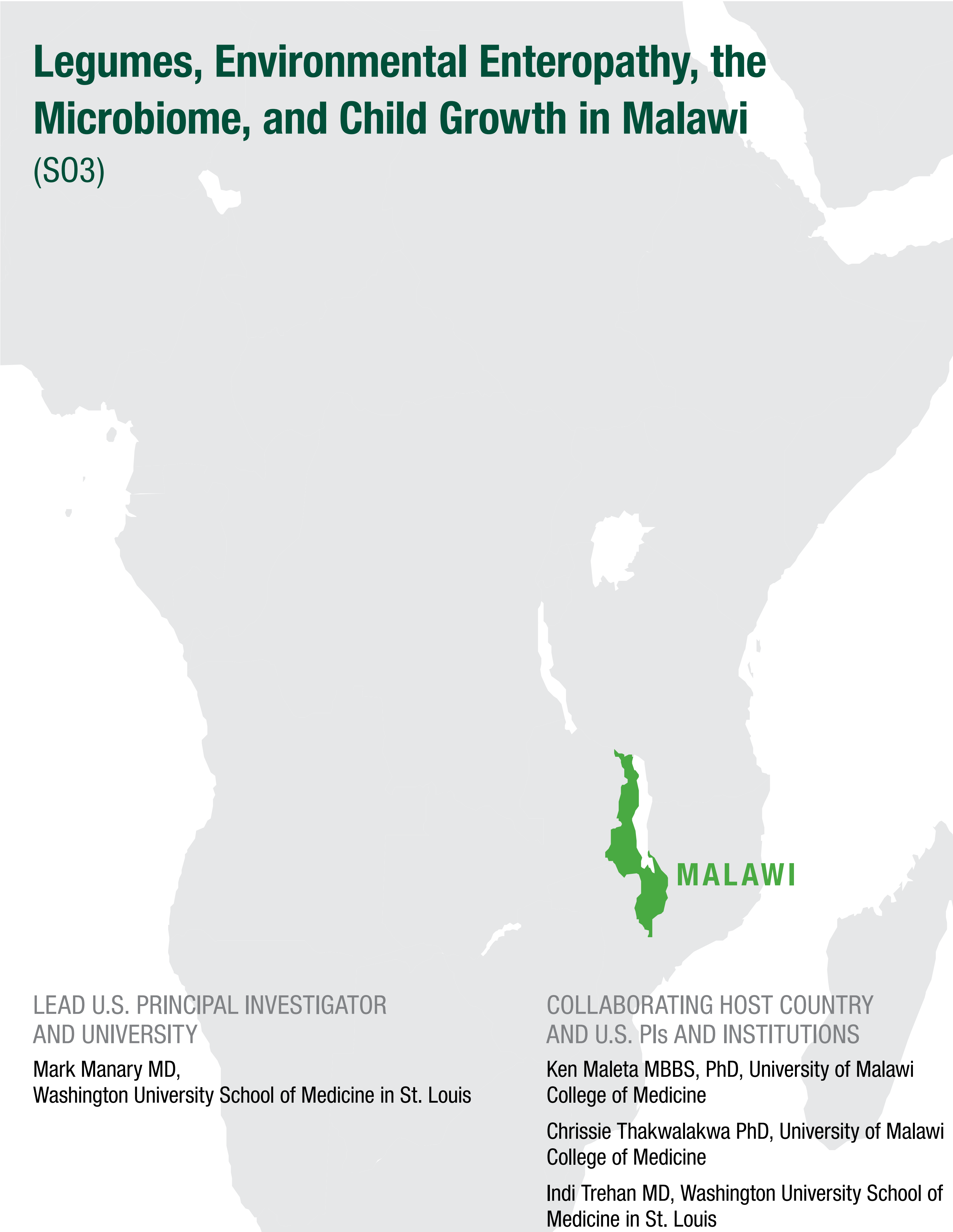
Scholarly Accomplishments

Mfikwa, Adelina E. and **Fredy T.M. Kilima**. 2014. Factors influencing the consumption of pulses in rural and urban areas of Tanzania. *Tanzania Journal of Agricultural Sciences* 13(2): 59-74.

Ross, K.L., V. Amanor-Boadu, and L. Mapemba. *Understanding Consumer Choice for Grain Legumes: Recent Evidence from Malawi*. Paper presented at the 90th Annual Conference, Western Economics Association International, June 28–July 2, 2015, Honolulu, Hawaii.

Legumes, Environmental Enteropathy, the Microbiome, and Child Growth in Malawi

(SO3)



LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

Mark Manary MD,
Washington University School of Medicine in St. Louis

COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

Ken Maleta MBBS, PhD, University of Malawi College of Medicine

Chrissie Thakwalakwa PhD, University of Malawi College of Medicine

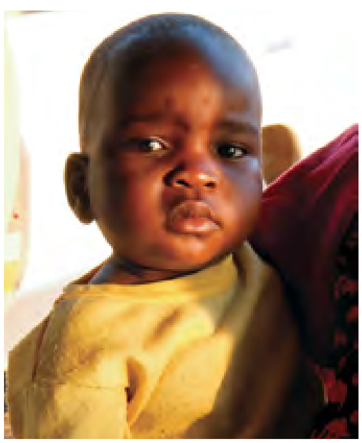
Indi Trehan MD, Washington University School of Medicine in St. Louis

Abstract of Research Achievements and Impacts

In FY 2014–15, this project initiated several activities to meet the objectives of evaluating changes in childhood anthropometry, biomarkers of environmental enteropathic dysfunction (EED), and the characteristics of the intestinal microbiome after inclusion of either cowpeas or common beans as an integral component of complementary feeding in two large cohorts of rural Malawian children. In FY13–14, the project obtained IRB approval, conducted acceptability trials to determine the food formulas, and created the operational manual that contains operating procedures for the duration of the trial. The operational manual was developed by Chrissie Thakwalakwa, who completed her PhD in Public Health Nutrition utilizing this study to complete her thesis. The local team implementing the clinical trial continues ongoing training in the principles of Good Clinical Practice. Two Malawian Master's-level students enrolled at LUANAR and two Malawian PhD students enrolled at the University of Malawi College of Medicine were identified and began work on the project. More than 50 percent enrollment in Study 1 and full enrollment in Study 2 have been completed.

Project Problem Statement and Justification

Successful interventions to help prevent children from becoming malnourished and achieve their full growth potential remain lacking. 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.



A young boy at a health post with his mother.

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 EED and improve growth among at-risk children. In this study, we are testing 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, since their local insights and knowledge of food systems and cultural feeding practices will help guide the optimal development and implementation of these bean flours at scale if they prove to be successful in reducing EED and stunting.

Preparing to take stool and blood samples.

III. Objectives

1. Develop a working *Manual of Operations* to conduct the research projects in the field.
2. Develop and test the acceptability of two sets of three to four recipes that include either cowpeas or common beans for use with infants in the clinical trial.

A mother and child participating in the double-blind feeding study for recently weaned children

3. Complete preparations to initiate study aim one, including staff recruitment, training, and community engagement and organization.
4. Increase the capacity, effectiveness, and sustainability of agriculture research institutions that serve the bean and cowpea sectors in Malawi.

Technical Research Progress

Objective 1. Develop a working Manual of Operations to conduct the research projects in the field.

The Manual of Operation to conduct the research projects in the field was developed by Chrissie Thakwalakwa with input from the rest of the research team. The study procedure guide describes the mode of operations for all study related participants and community interactions, including clinic operations, patient and participant screening, participant consent, enrollment, and food distribution. The manual also provides guidelines for data collection, giving instructions on surveys, home visits, anthropometric techniques, the collection of biological samples, and event reporting procedures for any unexpected and adverse events. The manual provides the field work directives for the field team.

Objective 2: Develop and test the acceptability of two sets of three to four recipes that include either cowpeas or common beans for use with infants in the clinical trial.

Dry formula made from either common bean or cowpea in jars for distribution.

The LUANAR graduate students developed food recipes using cowpeas and common beans. The recipes were developed in accordance with World Health Organization specifications and the candidate recipes underwent acceptability testing in Malawian infants with the support of the Malawi College of Medicine. The preferred flour recipes were selected and are being used in the clinical trials.

Objective 3. Complete preparations to initiate study aim one, including staff recruitment, training, and community engagement and organization.

All ethical approvals were obtained from the institutional review boards at the University of Malawi College of Medicine and Washington University in St. Louis. Two Food Science and Technology master-level students were recruited and enrolled at LUANAR. Additionally, two PhD students were recruited at the Malawi College of Medicine. All local staff were recruited and underwent extensive training in Clinical Good Practice techniques and data collection methods to properly conduct all enrollment and data collection. The field teams visited the areas near Masenjere in Nsanje District and Limela in Machinga District to mobilize and engage the district in the research project and started the study in these areas. More

Children participating in the trial are measured during the study.

than 50 percent enrollment in Study 1 and full enrollment in Study 2 have been completed. Meetings with local community leaders and health centers continue.

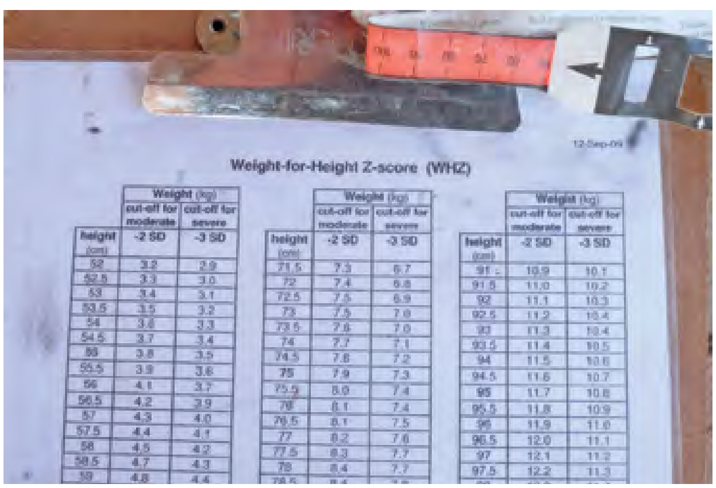
Objective 4: Increase the capacity, effectiveness, and sustainability of agriculture research institutions that serve the bean and cowpea sectors in Malawi.

The PI and the research team continue 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, continues to be supported by this project and provide 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 LUANAR master's students continued to be engaged in the clinical trials even after developing the food recipes and supervising bean sourcing, flour production, preparation, and safety monitoring of the intervention foods.

Children participating in the trial are weighed during the study.

Major Achievements

1. Development of the *Manual of Operations* to delineate procedures and guidelines for the conduct of the clinical trials.
2. Development and testing of multiple legume recipes and completion of an acceptability study involving more than 100 children to help determine the optimal recipes for use in the clinical trials.
3. More than 50 percent enrollment in Study 1 and 100 percent enrollment in Study 2. Enrollment required collaboration in the districts where the studies are being conducted, ethics approval, hiring and training of staff, and the development and selection of food formulas.



Records are kept of all measurements of each participating child throughout the study.

Research Capacity Strengthening

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 continues and will help to develop them 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, developed the study procedures, guidelines, and material for the study, and continues 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. A freezer was purchased that will be maintained at Washington University and utilized to store samples.

Human Resource and Institutional Capacity Strengthening

Short-Term Training

Two women from LUANAR received training in Malawi during 2014-2015 from Washington University in St. Louis on how to equip the local Malawian health institution with the tools needed to initiate and conduct operational health, nutrition, and agriculture studies. Specifically, they were trained in recipe development related to dietary interventions aimed at improving the health and wellness of the people of Malawi.


The families who come to participate in the study are presented with a gift in appreciation of their participation, in this case, an umbrella.

Short-Term Training: Staff Field Training

The University of Malawi College of Medicine conducted field training with six women nurses, four men drivers, and 11 men and four women village health workers in study guidelines, anthropometric data collection, biological sample collection, and community engagement, as appropriate to each trainee's need in regard to their research-support activities.

Achievement of Gender Equity Goals

Beneficial findings and knowledge gained from these studies will benefit both women and men in Malawi, both parents and children.

In terms of training future scientists, all but one of our Malawian graduate students are women. Both American graduate students are women. One of our nondegree American students is a woman.

The common bean- or cowpea-based formula, prepared.

Scholarly Accomplishments

Indi Trehan, Nicole S. Benzoni, Alfred Z. Wang, Lucy B. Bollinger, Theresa N. Ngoma, Ulemu K. Chimimba, Kevin B. Stephenson, Sophia E. Agapova, **Kenneth M. Maleta**, and **Mark J. Manary.** 2015. Common Beans and Cowpeas as Complementary Foods to Reduce Environmental Enteric Dysfunction and Stunting in Malawian Children: Study Protocol for Two Randomized Controlled Trials. *Trials.* 16: 520; doi: 10.1186/s13063-015-1027-0.

Nutrition education for mothers participating in the study with their children follows the medical examination and includes directions for properly making the cereal, which is prepared from either common bean- or cowpea-based flour.

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

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COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

Eric Crawford, Michigan State University

Robert Shupp, Michigan State University

Byron Reyes, CIAT

U.S. and HC PIs/collaborators of other Legume Innovation Lab Projects

Abstract of Research Achievements and Impacts

In FY 2015, this project worked towards completing or initiating several activities under its three objectives. A baseline survey in Guatemala was completed in close collaboration with the SO1.A1 team to help better evaluate the status of the climbing bean/maize intercropping production system.

Several research studies on the theme of sustainable seed systems were initiated, including a study on farmers' willingness to pay for different types of seeds in northern Tanzania and a case study on a farmer association in Burkina Faso involved in cowpea seed production through the training of farmer-members that included the provision of technical oversight for the production of quality declared seed for sale to other farmers in the community.

Two short-term training courses on the theory and methodology of impact evaluation were conducted in collaboration with CIAT and other national partners in the LAC region and East and Southern Africa regions.

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 policy makers and the public but must be augmented with empirical data and sound and rigorous analysis.

This project is designed to contribute toward 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 in achieving two important goals—accountability and learning. Greater accountability (and strategic validation) is a prerequisite for continued financial support from USAID and greater learning is crucial for improving the effectiveness of development projects and ensuring that the lessons from experience—positive and negative—are heeded. Integrating this culture of impact assessment in publicly funded programs such as the Legume Innovation Lab will ultimately help increase the overall impact of such investments.

Objectives

1. Provide technical leadership in the design, collection, and analysis of data for strategic input and impact evaluation.
2. Conduct ex ante and ex post impact assessments.
3. Build institutional capacity and develop human resources in the area of impact assessment research.

Technical Research Progress

Objective 1. Provide technical leadership in the design, collection, and analysis of data for strategic input and impact evaluation.

1a. Socioeconomic baseline study on the constraints and opportunities for research to contribute to increased productivity of climbing beans in Guatemala

This is a joint activity with the SO1.A1 project team. This study is designed to establish a baseline on production of climbing beans in the highlands of Guatemala and to better understand the current status of the climbing bean/maize intercropping production system.

In FY 2015, data collection from 548 farming households from five Feed the Future departments in Guatemala representing the highland bean growing regions was completed. A detailed household-level survey instrument was developed in Spanish jointly by the SO4-1 and SO1.A1 team. This instrument was then translated into English and submitted to the NDSU's IRB for approval. In March 2015, team members from the SO4.1 team traveled to Guatemala and trained 13 enumerators and four supervisors in data collection and data entry. The survey, designed to obtain a representative picture of the bean growers in the highlands from the five Feed the Future departments of Guatemala defined as areas 1500 meters (or more) above sea level, was conducted from March 9–27 by the trained enumerators as per the sampling plan developed by

SO4-1. Data were collected from an average of six randomly selected farm households from 87 villages across the departments of Chimaltenango, Quiché, Huehuetenango, San Marcos, and Quetzaltenango.

Data analysis is currently under way and will be completed in the next few months. The analysis will focus on the current status of the climbing bean–maize intercropping production system (*milpa*) in the highlands of Guatemala. Data concerning cultivated area, production practices, production problems and constraints, seed quality, and culinary preferences along with the sociodemographic characteristics of farm households will be analyzed using descriptive and econometric techniques to help establish priorities for the climbing bean breeding program.

1b. Study on the market potential for biopesticides in Benin

A collaborative activity with the SO1.B1 project team under their objective on the *scaling of solutions* was designed as a baseline to assess the market potential for biopesticides (e.g., what farmers would be willing to pay, what the costs would be to enter the market for such a small industry, what skill sets were needed for women's' groups to make and profit from selling such materials, etc.) and to determine the networks of NGOs and other organizations to which the project could pass-off educational approaches (e.g., animations) for scaling.

The Impact Assessment team provided technical support in the form of human resources and professional expertise in data collection (e.g., sample design, evaluation design, designing data collection instruments, training enumerators, data entry templates, etc.) and analysis. However, due to language constraints, the role of the SO4.1 project team in providing this technical assistance has been limited. Field work consisting of the following three phases was mostly completed by INRAB (with support from IITA) in FY 2015 and the progress report of this activity is reported in the SO1.B1 Annual Report.

1. Documentation phase: collection of secondary information
2. Exploratory survey in main cowpea production areas mainly through group interviews of major stakeholders in the value chain, but also to collect preliminary data for designing the individual survey questionnaire
3. Detailed survey with individual questionnaires administered to key players in the cowpea value chain, particularly targeting producers and consumers, and their willingness to pay for biopesticides and biopesticide-treated cowpea, respectively

Objective 2. Conduct ex ante and ex post impact assessments.

2a. Sustainability of legume seed system constraints and opportunities to guide policies and programs.

Motivation. Benefits from plant breeding research can only be transferred to farmers if an improved variety (IV) is released and good quality seeds of that improved variety are planted by farmers. Thus, gains from investments in plant breeding research depend on both the genetic improvement embodied in the seed as well as on the existence and performance of a seed system that can deliver improved genetics to farmers in good quality seed/planting material. Recognizing the importance of the seed system in delivering the benefits of plant breeding research, donors, governments, and research organizations working in development can add significant value to augment farmers' access to seeds of improved varieties. Many of these efforts require providing subsidized or free seed to farmers, which may not be sustainable in the long-term. Thus, there is a strong interest and need for research exploring alternative ways to make high quality low cost seed locally available to farmers and learning whether a seed market is latent in rural areas of developing countries.

One of the important factors that determines the sustainability of a seed system is the effective demand for seed of improved varieties as reflected in the volume and frequency of purchase of fresh seed by farmers. Even where farmers have adopted IVs, the low volume and low frequency of seed demand has often been cited as a major reason for the lack of private sector involvement in the seed system or the development of alternative models of a sustainable seed system. This is especially the case for self-pollinated crops like beans, since bean seed of the same variety/type/market class is highly competitive with bean grain as planting material. Since producing and marketing beans as seed involves taking specific and extra measures during seed production and postharvest processing to ensure quality, it is more costly to produce than buy bean grain. Also, complying with the country's seed regulatory requirements to sell the seeds as *certified seed* or *quality declared seed* (*QDS*) increases the cost. Keeping the genetics constant (i.e., for the same improved variety), the viability of a seed market depends on the co-existence of the following demand and supply side conditions.

On the demand side, it depends on 1. whether farmers are able to perceive the seed product as a quality planting material, and 2. given the perceived quality difference, whether they are willing to pay a premium price for seed compared to grain. On the supply side, it will depend on whether the price farmers are willing to pay is high enough to recover the cost of producing quality seed and whether the quantity and frequency of seed demanded at that price is large enough to attract suppliers to produce and sell quality seed. There are no rigorous studies that have examined these demand and supply side dynamics in a systematic manner. The following project activities attempt to address these questions for grain legumes.

2a-i. Assessment of the willingness of smallholder farmers to pay for quality seed.

This study was conducted in close collaboration with Sokoine University of Agriculture and CIAT in northern Tanzania, where four types of seed products are potential options available to farmers as planting materials—certified seeds produced from foundation seed (certified 1), certified seed produced from certified 1 seed (certified 2), quality declared seed (QDS), and recycled seeds (saved from a farmer's own harvest). These four types of seeds or planting materials differ in seed input (i.e., which generation of seed is used to produce them), the regulatory supervision they receive or don't receive, and the technical conditions under which they are produced—and thus vary in cost. However, whether the cost differential across these types of seeds makes them qualitatively different products as reflected in the perceived or actual performance of the plant, and whether that translates into differential prices that farmers are willing to pay is an empirical question rarely addressed in the literature.

This study is based on field experiments (FE) and bidding experimental auctions (BEA) proposed in two districts in northern Tanzania to gauge the demand for bean seed of different types and to collect systematic data from seed consumers (i.e., farmers) to understand the economics of the seed system from the demand side. The study is designed to address the following research questions:

1. For a given improved variety, what is the difference in performance (as measured by yield and other characteristics important to farmers) of bean crop across the four seed types when the seeds are planted and managed by farmers under their conditions?
2. How does the observed differential performance of different types of seeds translate into farmers' willingness to pay (WTP) for these seeds?

Due to delays in finalizing the contractual mode for transferring the funds to SUA, the FEs were conducted in only one district this reporting year. The FEs were planted in July 2015 under irrigated conditions and were based on the following methodology.

Methodology. To address research questions one and two, a two-step approach was used. First, double-blind field experiments were established in six hamlets across Kawaya, Kikavu chini, and Chemka villages in the Hai district (in the Kilimanjaro region, northern Tanzania). The FE were used to demonstrate the value of planting certified 1 vs. certified 2 vs. QDS vs. recycled seed of the bean variety *Jesca*, so farmers could see first-hand the difference in the agronomic performance of the plants, the amount harvested, and the quality of the beans. Through these experiments, farmers were able to observe how different grades of seeds of the same improved variety perform in a location close to their farm. Second, once farmers observed how different grades of seeds of a particular variety performed, experimental bidding auctions were conducted to extract information about how much they were willing to pay for these seeds based on the observed differences in their performance.

The FEs were set up as a double-blind experiment, where neither the farmers nor the agricultural extension officers knew the types of seeds included in the study. Technical staff implementing the FE and farmers knew the variety (i.e., *Jesca*), and that there were four grades of seed planted on that plot, randomly labeled A, B, C, and D, but they were not told which code represented each seed type. The same seed codes used in the FE were used throughout the study to be able to match all the information collected.

The FEs were planted on a 100 sq. m. (10m x 10m) subplot with a total plot of 400 sq. m. of land. The amount of seed required for this area was one kg. The field experiments were planted in a farmer's field with host farmers in charge of planting and managing the FE following their own management practices (i.e., they were not managed as experimental trials). Partners (SUA and agricultural extension officers from selected districts) selected the host farmers, delivered the seed for the FE to them, and supervised the establishment of the FEs. During the production cycle, two field days were carried out in the two best performing fields in each village. All farmers living in the village were invited to see the bean plots and learn about their performance. The first field day was conducted around the flowering stage and the second was held just before or after harvest. Attendees at the first Field Day were given a sheet for ranking the subplots according to a set of criteria agreed upon by the farmers. During the second field day, the same attendees were asked to rank the best and the worst subplots and the reason for their ranking. The data collected from the FE during the two field days and the yield data from the harvest will be used to estimate the per unit gain from planting different types of seeds under farmer conditions.

The Bidding Experimental Auctions were conducted to determine how much farmers would be willing to pay for the different types of seeds during the second field day. We followed the Becker-DeGroot-Marschak method, in which participants did not bid against other people, only against themselves. Prior to the seed BDM auction, a practice BDM was conducted with a bar of soap to make sure farmers understood the auction mechanism.

The willingness to pay (WTP) elicitation mechanism was performed using a full bidding method. In this method, farmers were first endowed with TS 4000 (equivalent to about U.S. $2) to make their decisions more realistic and then asked to participate in four auctions by bidding their maximum WTP for one kg of each seed type. Farmers were told that one of the four auctions would be chosen randomly and the bid for that seed would then be compared to a randomly drawn number from a given revealed price range of TS 0 to 3950. If the bid were greater than or equal to the randomly drawn price, then the farmer would buy that seed at the randomly drawn price (not his/her bid price). The difference in the bids between the four auctions revealed the premium (or discount) due to the different seed type grades. In this method, the farmer is likely to pay less than his/her bid (unless the bid and random price are equal) and, thus, the auctions are, theoretically, an incentive compatible with eliciting true farmer WTP.

A total of 114 farmers participated in the BEA across the three villages. Survey data were collected from each farmer who participated in the auction to gather their socioeconomic demographics and experience with producing beans, varietal use, and prior use of different grades of seed. Analysis of data is currently ongoing.

Tanzania was selected for this study because it officially recognizes quality declared seed (QDS), making it interesting to compare the performance of QDS to certified seed and then assess farmers' willingness to pay for these two types of seed, which have different production costs.

2a-ii. Case study on a community-based seed system

In FY 2015, this project initiated a case study of a farmer association in Burkina Faso, *Association Song Koaadba* (ASK), which currently has about 7,500 members over 58 villages in the provinces of Oubritenga, Kourweogo, Kouritenga, Ganzourgou, Sanmatenga, Passore, and Sissili. According to the ASK management team, in 2014 approximately 80 ha of land was devoted to cowpea seed production by about 125 members. ASK members involved in seed production mostly produce QDS seeds of cowpea for sale to other ASK members and nonmember farmers in their communities. Over the past 20 years, ASK has had strong ties with INERA and has received continuous guidance and technical support from them in strengthening their cowpea seed production. In turn, ASK has served as an effective organization for INERA to channel new and improved cowpea varieties, generated by its cowpea breeding program to.

The long-term sustainability of ASK's business model is rare to encounter in a developing country. This study was motivated by ASK's longevity in cowpea seed production and sale (20 years) and was designed to:

1. Document the cowpea seed production and distribution model used by ASK,
2. Collect and analyze data to understand the economics of community-based smallholder seed production, and identify strengths and weaknesses of the model used by ASK, and
3. Derive principles of sustainability underlying the model used by ASK for broader applicability within Burkina Faso and other countries.

Methodology. The case study uses a combination of qualitative and quantitative methods to achieve the above objectives. The qualitative method includes conducting key informant interviews (KII) with ASK's management and technical team and backward linkage partners, such as the suppliers of foundation seed (i.e., INERA) and forward linkage partners, i.e., buyers of the seed produced. The following KII were completed by the host country collaborators between February and June 2015.

1. KII with ASK management team: Types of information collected from these interviews include ASK's history, current operation, aspirations for the future, and a descriptions of its activities, sources of financial support, organizational and governance structure, seed production, and marketing activities, and the management teams' perception and opinion on key challenges, strengths, and weaknesses.
2. KII with INERA: The cowpea seed program management staff were interviewed for their perspectives on the demand for foundation seed by ASK, their perspective on key challenges to meet this demand, and the strengths and weaknesses of the ASK model.
3. KII with SNS (National Seed Service) and UNPS-Union Nationale des Production Semenciers de Burkina. Representatives of these agencies were interviewed to gather information to better understand the formal seed system in Burkina Faso, obtain an overview of the annual production and sale of certified seeds of cowpea in the country, the certified seed production value chain, seed policy environment, key challenges, strengths, and weakness of the formal seed system, and their perspective on the role played by ASK in the seed system.
4. KII with two organizational buyers of seed produced by ASK to gauge their evaluation of the seed quality, ability of ASK to meet their need for cowpea seed, and their perspective on key challenges to meet this demand, and the strengths and weaknesses of the ASK model.

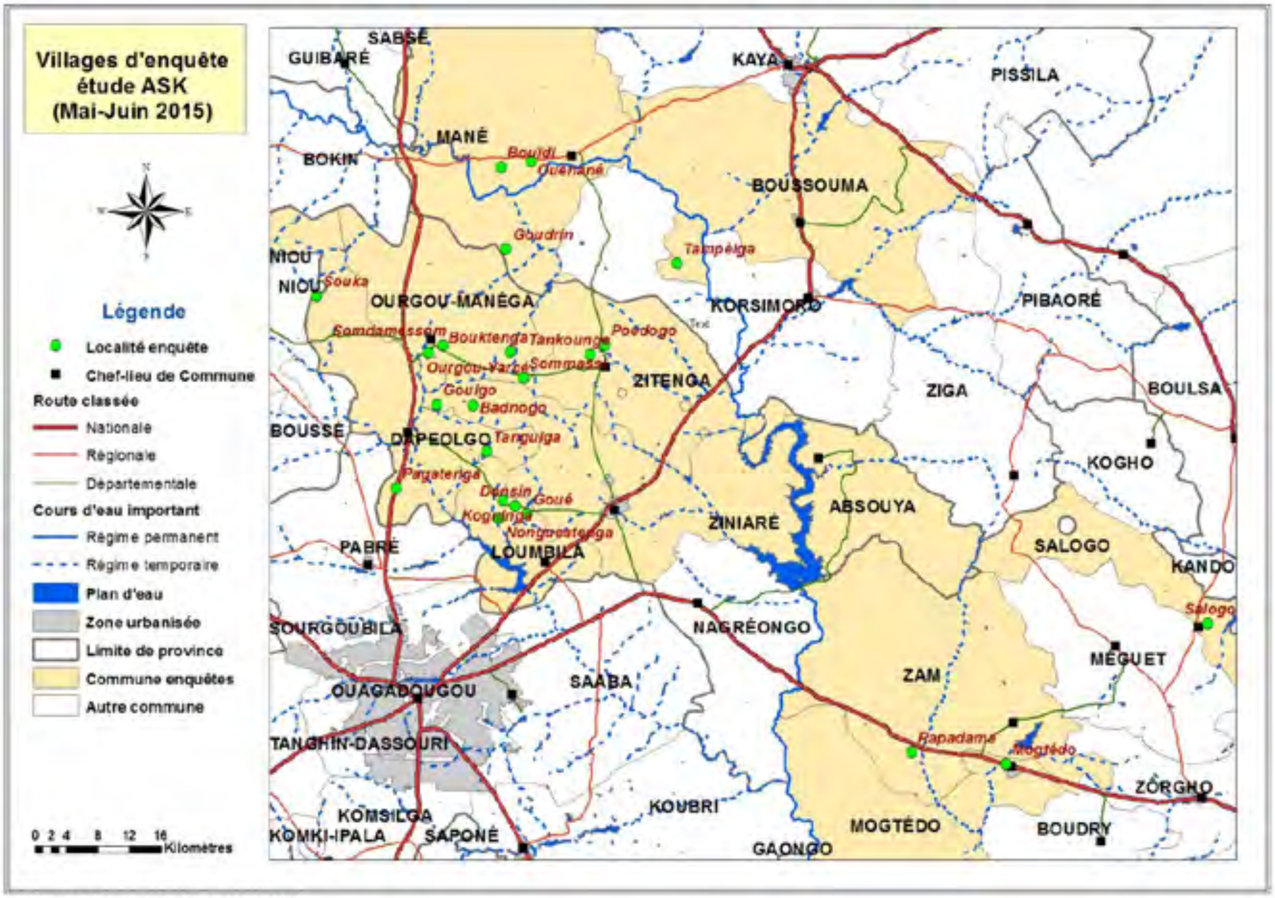
The quantitative method used to achieve the objectives of this study included the following types of data collection:

1. Secondary data from the Ministry of Agriculture, SNS, UNPS, etc. on cowpea area, production, yield (most recent year by district or lowest administrative unit)
2. Historical price data of cowpea grain
3. Historical price data of certified seeds of cowpea
4. Historical data of certified cowpea seed production
5. Conducting surveys of a sample of cowpea seed producers and seed buyers using structured questionnaires

For this later activity, a list of all the villages where ASK members reside was obtained from ASK with the following information: the year in which that village became a member of ASK, the number of ASK memberships, and the number of cowpea seed producers (as of 2014). Twenty-five of 58 villages were randomly selected from the list of seed producing villages (14) and nonseed producing villages (11). In each village, nine farmers were randomly selected to represent seed producers, ASK members, and non-ASK cowpea farmers. In total, 225 farmers (54 seed producing farmers, 98 ASK member farmers, and 73 non-ASK member farmers) were surveyed from May to June 2015 using a structured questionnaire. A community-level questionnaire was also completed for each of the 25 villages visited. The distribution of these 25 village communities surveyed is given in figure 1. The survey was completed in September. Analysis of the information obtained through KII and the farmer survey is planned and a report summarizing the results of this case study will be shared with the Management Office and USAID in early 2016.

2b. Impact study in Haiti

During the past 20 years, with support from USAID, the National Seed Service of the Ministry of Agriculture in Haiti has conducted bean research in collaboration with the University of Puerto Rico, the USDA-ARS, and Zamorano. This collaboration resulted in the development and release of such bean cultivars as DPC-40, XRAV-40-4, MEN 2201-64ML, and *Aifi Wuriti,* which have greater disease resistance, improved agronomic traits, and higher seed yield potential than local landrace varieties. In recent years, the Bean Technology Dissemination (BTD) project in Haiti received funding from USAID to produce and distribute 69 MT of seed of these improved bean cultivars to more than 25,000 farmers. Some of the NGO's, such as Zanmi Agrikol and Helping Hands, which participated in the production of bean seed, continue to produce seed of the improved varieties.



Sources : BNDT_MajBGB, projet ASK

Figure 1. Location of villages selected for ASK seed producer and member surveys in Burkina Faso (villages are indicated by green dots).

Despite these recent and long-term investments in bean research and the dissemination of improved variety seeds, there is no study conducted by NSS, the Ministry of Agriculture, or the National Agricultural Statistics Service in Haiti to assess the adoption of these technologies and their impact. Last year, the SO1.A4 team expressed a strong interest in conducting an impact study in Haiti with technical assistance from this project team.

Due to elections in Haiti in 2015, the host country collaborators suggested conducting this study in 2016, instead; this recommendation was accepted.

Objective 3. Build institutional capacity and develop human resources in the area of impact assessment research.

This project completed the following activities in FY 2015:

1. Research studies conducted in Guatemala, Burkina Faso, and Tanzania under objectives one and two involved host country PIs, collaborators, and 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 the training of enumerators and field staff in data collection, data entry, and analysis.
2. Activities planned under this project involved graduate students in the planning and conducting of field research and the writing up of research results.
3. Short courses on impact assessment. Two short-term training workshops to build capacity of local partners were implemented in collaboration with CIAT and other NARS partners. These workshops focused on teaching theoretical concepts and demonstrating practical applications of these concepts to rigorously assess the impact of agricultural projects and programs. The topics included current theory and methods on impact evaluation, sampling methods, data collection instrument design, data collection using computer assisted personal interviewing software and paper questionnaires, and the use of statistical software for data cleaning and analysis.

Major Achievements

- Factors positively contributing to the sustainability of community-based seed production include the importance of training (seed marketing and business skills), ownership of productive assets (especially silos), experience of leadership, cost recovery, quality and quantity of seed produced, and operational formality in the form of conducting meetings and documenting decisions made at meetings.

- Community-based seed bank models provided a production and delivery model that lasted longer than individual banks. The policy implication of this result is that CSBs present a more sustainable dissemination channel of improved variety seed to farmers than small-scale contract-based seed production by individual farmers.

Research Capacity Strengthening

IIn FY 2015, an intensive one-week, short-term training workshop was implemented towards capacity strengthening in monitoring and impact evaluation, through the Supplemental Institutional Capacity Strengthening funds provided to ZARI. Researchers and economists from IIAM, LUANR, ZARI, SUA, Makere University, and EIAR were invited to attend this training workshop in Lusaka, Zambia, in September 2015. This course was led by Legume Innovation PIs and economists from CIAT.

Human Resource and Institutional Capacity Development

Short-Term Training

CIAT and MSU sponsored a workshop in Montevideo, Uruguay, from May 18 to 22 that was held for 19 people (10 men and nine women) to strengthen the capacity of research and development organizations to document the results and impacts related to the development of agricultural technologies. Uruguay, Argentina, and Brazil benefitted from the training.

MSU and CIAT sponsored a training workshop in Lusaka from September 21 to 25 for 16 people (12 men and four women) to strengthen the capacity of research and development organizations to document the results and impacts related to the development of agricultural technologies. Zambia, Mozambique, Malawi, Tanzania, Uganda, and Ethiopia benefitted from the training.

Legume Innovation Lab Human and Institutional Capacity Development

FY 2015 Summary Report

Legume Scholars

The Legume Innovation Lab, in partnership with the Feed the Future Innovation Lab for Collaborative Research on Peanuts and Mycotoxin Management Office and the CGIAR's Research Program on Grain Legumes, obligated $1,250,000 to support the *Legume Scholars Program* (LSP). The LSP objectives are:

1. 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,
2. To facilitate greater collaboration in research between the CGIAR and the USAID Innovation Lab legume scientists through joint supervision of graduate student research projects, and
3. 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.

The agreement between the three partner institutions was that the LIL Management Office would assume responsibility for administration of the scholarship program.

In November 2014, a Request for Nominations for Legume Scholars Program scholarships was distributed internationally to NARS, CGIAR centers, international grain legume research programs, and collaborating host country institutional partners in the Legume Innovation Lab. Two hundred forty-eight nominations packages were submitted for the program by late December 2014, the overwhelming majority for young African trainees from diverse countries interested in pursuing a Master's or PhD program.

The LIL Management Office and its partners in the Peanut and Mycotoxin Innovation Lab and the CGIAR Research Program on Grain Legumes reviewed the 210 complete nomination packages. From this pool, 37 nominees were invited to take the GRE and TOEFL exams to assess their admissibility into graduate programs at U.S. universities. Based on this information and references, the Legume Scholars Selection Committee chose five individuals to receive four-year scholarships for PhD degree study under the guidance of an Innovation Lab PI. Each scholar also has a CGIAR scientist associated with his/her study and research program.

The scholars and their research project plans are as follows:

1. **Ms. Rosemary Bulyaba (Uganda)** will be investigating the integrated crop management of common bean in the Agronomy Department at Iowa State University under Dr. Andrew Lenssen.
2. **Mr. Aggrey Gama (Ghana)** will be investigating groundnut value addition and safety in the Food Science and Technology Department at the University of Georgia under Dr. Koushik Adhikari.
3. **Ms. Pacem Kotchofa (Benin)** will be investigating the cowpea value chain in the Department of Agricultural Economics at Kansas State University with Dr. Vincent Amanor-Boadu. The CGIAR IITA grain legume research scientist who will be co-supervising Ms. Kotchofa's doctoral research will be Dr. Ousmane Coulibaly.
4. **Ms. Susan Mokongu Moenga (Kenya)** will be investigating drought resilience of chickpea in the Plant Biology Department at the University of California, Davis, under Dr. Douglas Cook.
5. **Mr. Isaac Osei-Bonsu (Ghana)** will be investigating photosynthesis in grain legumes in the Plant Biology Department at Michigan State University under Dr. David Kramer.

Graduates from the program will further strengthen the research capacity of institutions in their home countries committed to the growth and development of the legume sector through scientific inquiry.

Training

Short-Term Training Programs

Twenty-one short-term training programs were conducted through LIL projects. The project researchers, US and host country, identified the training needs to meet local needs. The topics ranged from specific research methodologies for scientists to farmer field school approaches on production and storage methods as well as private sector business training to enhance grain legume value chains. A total of 3,215 men and 3,042 women participated in these short-term training activities, mostly held in Central America and Sub-Saharan Africa.

Long-Term Degree Training

Long-term degree training has always been a fundamental part of the collaborative research sponsored through the Legume Innovation Lab. Degree candidates are incorporated into the research as partners, learning the theory and practice of the scientific method. Often these students have research assistantships that ensure they are part of a professional team of researchers, with responsibilities and intellectual ownership of the research conducted. Each student is mentored by an internationally recognized legume researcher, establishing a long-term professional relationship with their advisor and a community of legume researchers.

Number (by gender and other characteristics)

Legume Innovation Lab projects funded, fully or partially, 46 female students and 54 male students, for a total of 100 students in university degree programs. There were 27 students in BSc programs, 47 in MS programs, and 26 in PhD programs. Of those students in degree training, 70 were studying at African or Latin American Universities, one in a European University, and 29 in U.S. universities. Some of these students completed their degree programs within FY 2015 and some began their programs during the fiscal year. Among the students, there are 70 of African nationalities, 22 from Central America, and eight from the U.S. Many students are only partially funded under the Legume Innovation Lab, with research costs or other aspects of their training program covered.

Institutional Capacity Strenthening

As in years past, the Legume Innovation Lab invited proposals from Principal Investigators (PIs) in the host countries to apply for materials or in support of activities that will contribute to enhancing the capacity of their institutions. A total of $200,000 was budgeted in the *Cost Application for Institutional Strengthening Awards* during FY 2015. This funding provides resources to complement the existing research funds through LIL projects, often contributing to enhancing facilities or providing additional training on the use of new technologies. These investments in human resource development, scientific equipment, laboratory and field facilities, computer technology, and infrastructure are prized by our host country nationals because they address critical needs in their research institutions.

In response to the solicitation in FY 2015, the Management Office received 15 proposals from partner host country institutions. Based on the TMAC's evaluations and recommendations, MSU obligated a total of $279,806 to 11 partner institutions in 10 host countries in support of institutional strengthening activities associated with seven subcontracted projects.

The list of institutions and host countries benefitting is presented in the table below.

Host Country Partners—Benefitting from LIL FY 2015 Institutional Strengthening Awards Partners

Project No.	Project	Host Country	Institution	Award Letter Amount
1	S01.A1	Guatemala	ICTA	$19,998
2	S01.A4	Haiti	NSS	$17,697
3	S01.A4	Kenya, Rwanda, Malawi, Angola	UPR	$24,263
4	S01.A5	Burkina Faso	INERA	$25,000
5	S01.B1	Niger	INRAN	$25,960
6	S01.B1	Burkina Faso	INERA	$36,300
7	S02.1	Mozambique	IIAM	$25,000
8	S02.1	Kenya	Makerere	$29,999
9	S02.2	Malawi	LUANAR	$38,864
10	S03.1	Malawi	University of Malawi	$20,350
11	S04.1	Zambia	ZARI	$16,375
Total				**$279,806**

All amounts rounded to the nearest dollar.

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