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 2016

USAID
FROM THE AMERICAN PEOPLE

Legume Innovation Lab

On the front cover:

A producer of certified bean seed in Honduras, Mr. Aguilera, shows his pleasure with the high yield and excellent grain quality of *Paraisito Mejorado 2 (PM2-Don Rey)*, a new variety of the small red seda seed-type bean developed by EAP-Zamorano in collaboration with the University of Puerto Rico with support from the Feed the Future Legume Innovation Lab. This new drought-resistant variety with high yield potential is characterized by its preferred seda-type red color and excellent flavor. In addition to appealing to consumers, seda-type beans are preferred for export and offer expanded market opportunities. In the field, PM2-Don Rey is resistant to Bean Common Mosaic Virus and Bean Golden Yellow Mosaic Virus, two prevalent diseases in Central America that can cause up to 90 percent grain yield losses in susceptible varieties.

Growing beans in Central America has never been easy. With the introduction of *Paraisito Mejorado 2-Don Rey*, however, farmers now have access to a technology that not only provides hope for increased yields in the field but also expanded market opportunities and income along with better flavor for household consumption. Conventional plant breeding techniques and marker-assisted selection were used by Feed the Future Legume Innovation Lab geneticists to breed this and other improved dry bean varieties.

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

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

FY 2016 Technical Highlights

October 1, 2015–September 30, 2016

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Legume Innovation Lab

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Abbreviations and Acronyms

AAI....................Alpha-Amylase Inhibitor

AATF.................African Agricultural Technology Foundation

ADP ....Andean Diversity Panels

ALS...................Angular Leaf Spot

ANT...................Anthracnose

AOR ....Agreement Officer's Representative, USAID

ARS ....Agricultural Research Service (USDA)

ASK...................Association-Song-Koaadba

ATA ....Ethiopian Agricultural Transformation Agency

BCMNV...........Bean Common Mosaic Necrosis Virus

BCMV..............Bean Common Mosaic Virus

BEA...................Bidding Experimental Auctions

BGYMV ....Bean Golden Yellow Mosaic Virus

BHEARD.........Borlaug Higher Education for Agricultural Research and Development Program

BIC....................Bean Improvement Cooperative

BNF ....Biological Nitrogen Fixation

Bt ....Bacillus thuringiensis

BTD...................Bean Technology Dissemination

CA ....Central America (includes Guatemala, Honduras, El Salvador, Nicaragua, and Costa Rica)

CBB ....Common Bacterial Blight

CCARDESA.....Centre for Coordination of Agricultural Research and Development for Southern Africa

CEDO ....Community Enterprise Development Organization

CEID ....Center for Interdisciplinary Studies and Development

CERAAS..........Centre d'Etudes Régional pour l'Amélioration de 'Adaptation á la secheresse

CGIAR.............Consultative Group on International Agricultural Research

CIAT..................Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)

CLUSA ....Cooperative League of the USA

CNRA ....Centre National Recherches Agronomiev

COSP ....Cowpea Out-Scaling Project in West Africa

CRI....................Crops Research Institute (Kumasi, Ghana)

CRP ....Consortium Research Program

CRSP ....Collaborative Research Support Program

CSB ....Community Seed Bank

CSD ....Community Seed Depot (MASFRIJOL) equivalent to CSB

CSIR ....Council for Scientific and Industrial Research (Ghana)

DARS...............Department of Agricultural Research Services

DCO..................District Commercial Officers

DDL ....Development Data Library

DEC ....Development Experience Clearinghouse

DEPI ....Dynamic Environmental Phenotyping Imagery

EAP..................Escuela Agrícola Panamericana–Zamorano (Honduras)

EED..................Environmental Enteric Dysfunction

FAO..................Food and Agriculture Organization

FMS ....Farmer Management System

FSRP ....Food Security Research Project

FTF ....Feed the Future

GALA...............Grain and Legume Association

GBS ....Genotyping-by-Sequencing

GWAS..............Genome-Wide Association Study

HC....................Host Country

HDDS ....Household Dietary Diversity Score

HIS...................High Input System

HYPERS ....Hyperspectral Imaging

IARC ....International Agriculture Research Center (of the CGIAR)

ICM ....Integrated Crop Management

ICRISAT ....International Crops Research Institute for the Semi-Arid Tropics

ICT ....Information Communication Technology

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 de Burkina Faso

INRAN............. Institut National de la Recherche Agronomique du Niger

INTA.................Instituto Nacional de Tecnologías Agrícolas (Nicaragua)

IP......................Innovation Platforms

IPM ....Integrated Pest Management

IPM-omics.......Integrated Pest Management-omics

IPs....................Innovation Platforms

ISRA ....Institut Sénégalais de Recherches Agricoles (Senegal)

ISU ....Iowa State University

IV ....Improved Variety

IYP....................International Year of Pulses

KII......................Key Informant Interviews

KSU ....Kansas State University

LD ....Linkage Disequilibrium

LIL.....................Feed the Future Innovation Lab for Collaborative Research on Grain Legumes or Feed the Future Legume Innovation Lab

LSMS-ISA ....Living Standards Measurement Survey – Integrated Survey on Agriculture

LSP ....Legume Scholars Program

LUANAR ....Lilongwe University of Agriculture and Natural Resources

MAGIC ....Multiparent Advanced Generation Inter-Cross

MAHFP ....Months of Adequate Household Food Provisioning

MAMEDICOT..Masaka Microfinance and Development Cooperative Trust

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

MSD ....Mean Square Differences

MSPAS.............Ministerio de Salud Pública y Asistencia Social, Guatemala

MSU ....Michigan State University

NaCRRI............National Crops Resources Research Institute (Uganda)

NARS ....National Agriculture Research System(s)

NDSU ....North Dakota State University

NGOs ....Nongovernmental Organizations

NSS ....National Seed Service (Haiti)

PABRA ....Pan-African Bean Research Alliance

PARTI ....Platform for Agriculture Research and Technology Innovation

PaViDIA............Participatory Village Development in Isolated Areas

PCA ....Principal Component Analysis

PCCMCA.........Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales

PHA ....phytohemagluttin

PHI ....Pod Harvest Index

PI.......................Principal Investigator

QDS..................Quality Declared Seed

QTL...................Quantitative Trait Loci

RALS................Rural Agricultural Livelihoods Survey

RCBD ....Randomized Complete Block Design

RESOPP ....Le Réseau des Organisations Paysannes et Pastorales du Sénégal/Network of Farmer and Livestock Organizations of Senegal

RIL ....Recombinant Inbred Lines

RMC ....Research Management Committee

SABREN ....Southern African Bean Research Networks

SARI ....Savannah Agriculture Research Institute (Tamale, Ghana)

SAWBO...........Scientific Animations Without Borders

SCAR...............Sequence Characterized Amplified Regions

SEMEAR..........Improved Seeds for Better Agriculture/Moçambique Sementes Melhoradas para uma Agricultura Renovada

SNF..................Symbiotic Nitrogen Fixation

SNP ....Single Nucleotide Polymorphism

SO....................Strategic Objective

SUA ....Sokoine University of Agriculture (Morogoro, Tanzania)

TAT...................Tepary Adaptation Trials

TDP..................Tepary Diversity Panel

TMAC ....Technical Management Advisory Committee

UCR..................University of California, Riverside

UNL ....University of Nebraska, Lincoln

UNPS ....Union Nationale des Production Semenciers

UNZA ....University of Zambia

UPR ....University of Puerto Rico

USDA...............United States Department of Agriculture

Vis/NIRS..........Visible and Near-Infrared Reflectance Spectroscopy

WUSTL............Washington University in St. Louis

ZARI ....Zambian Agriculture Research Institute (Zambia)

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Host Countries and Feed the Future Legume Innovation Lab Projects

West Africa

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

East and Southern Africa

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

Latin America and the Caribbean

Guatemala (SO1.A1, SO1.A4, and MASFRIJOL)
Haiti (SO1.A4)
Honduras (SO1.A4)

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

Subcontracted International Institutions

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

Preface

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

Throughout the world today, almost 800 million people suffer from chronic undernourishment, 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, where one in eight people are chronically hungry, 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, chick peas, 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 29, 2017) of the Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (Legume Innovation Lab [LIL]), 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 2016 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 highlights the technical progress and achievements made by Legume Innovation Lab projects during FY 2016, 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.

- The first proofs-of-concept for the complete quantitative trait loci (QTL) mapping process for photosynthetic properties in common beans using the PhotosynQ were completed at the University of Zambia. (SO1.A2)

- Researchers identified new bean sources of resistance to anthracnose, angular leaf spot, common bacterial blight, and rust in Uganda and Zambia. (SO1.A3)

- Experimental analysis of field data has shown that the use of animated educational videos is as effective in farmer education as the use of extension agent presentations. This information could help distribute educational resources to smallholder farmers. (SO1.B1)

- The early maturing black bean line MEN2201-64ML, which is resistant to the Bean Golden Yellow Mosaic Virus (BGYMV), the Bean Common Mosaic Virus (BCMV), and Bean Common Mosaic Necrosis Virus (BCMNV), was released in Honduras as *Lenca Precoz*. (SO1.A4)

- A research study on sustainable seed systems focused on farmers' *willingness to pay* for different types of bean seeds (Certified, Quality Declared, or Farmer Recycled) conducted in northern Tanzania clearly demonstrated that resource-poor farmers were willing to pay a premium for quality seeds (in this case, Certified Seed that showed better yields in field tests they observed), provided the price differential did not vary greatly (e.g., 1 to 2.3 percent) from the average price of market grain. In summary, farmers' willingness to pay for premium seed decreases as the price of seed increases, with 70 percent willing to pay a bit more than the price of grain (1 to 1-plus percent more) but only 20 and 10 percent, respectively, when the price exceeded 1.5 and 2.3 percent of the grain price. (SO4.1)

- The mitochondrial genomes of cowpea aphid populations from Ghana and California were completely sequenced and compared for their relatedness. (SO1.A5)

- Value chain researchers developed a recipe contest to help consumers consider beans as a main course versus just a relish or small side dish. (SO2.2)

I encourage you to read the *FY 2016 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 Feed the Future 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 Feed the Future Legume Innovation Lab is making tangible contributions to the nutritional 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
Feed the Future Legume Innovation Lab
Michigan State University

A project researcher illustrates the large size of a climbing bean pod in Guatemala.

Genetic Improvement of Middle-American Climbing Beans for Guatemala

(SO1.A1)

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Abstract of Research and Capacity Strengthening Achievements

The project continues to make progress toward the testing and release of improved climbing beans for the highlands of Guatemala. Ten lines have been tested across more than 15 locations in farmers' fields to obtain information on their agronomic performance as well as growers' feedback. Results from farmer field trials during the 2016 growing season will be needed before making final decisions regarding release of varieties.

Three lines are showing the best combination of seed yield and reduced aggressiveness that would allow high productivity in the maize under the milpa system. On-farm testing of Bolonillo Texel, Labor Ovalle, and Utatlan continued during FY 2016 to ensure adaptation and acceptability by growers. Genetic purification of Bolonillo-Texel is in its last stages to insure that a homogeneous variety is released. Although this is not a major issue for growers, such homogeneity will facilitate seed production of this variety in the future.

The climbing bean collection was received at NDSU and genotyping of the collection has been conducted as planned. Approximately 150,000 SNP markers were used to characterize a nonduplicated subset of 420 accessions from this germplasm collection. Preliminary results show that this population is structured as an admixture of genotypes with no clear separation into subgroups. Genetic relationships with other races, gene pools, and species are currently under study. Approximately 95 percent of the seed samples obtained from the growers' survey were successfully increased at the ICTA greenhouses and were characterized in the field during the 2016 growing season. These seed samples create a great opportunity to assess the current genetic diversity being planted by growers and to compare them with the original climbing bean germplasm collected 30 years ago. Preliminary results from the growers' survey have allowed a better understanding of the current situation of climbing bean production and consumption in this region.

The three students (two female, one male) recruited to do their MS training in plant breeding and genomics at NDSU continue to make progress; their programs should be completed by FY 2017. Their education will help ensure the next generation of bean scientists for Guatemala.

Project Problem Statement and Justification

With approximately 11 million habitants, 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. With few other sources of protein available, this amount is insufficient to ensure a nutritionally complete diet, especially within poor households. Chronic malnutrition is frequent among children younger than five years in the western highlands—and 67 percent of them are adversely affected, with one-third of children from six to 59 months there showing some degree of anemia. Approximately 18 percent of reproductive-age women also exhibit anemia, with 29 percent prevalence among pregnant women and 23 percent prevalence among breastfeeding women.


A climbing bean field growing in Guatemala's highlands

Beans are grown on 31 percent of the agricultural land and mostly in the low to mid-altitude regions (0–1500 masl) in a monoculture system. Contrastingly, intercropping (locally known as *milpa*) is the main cropping system in the highlands, where maize–bean is the most common crop association. Unfortunately, on-farm productivity of climbing beans is approximately one-third of its 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 causes of yield reductions. In addition, farming is done with almost no inputs of fertilizers and/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. Research projects have been involved in collaborative bean breeding research targeting lowland agroecologies in Central America for many years, but research on the highland bean production systems is lacking.

There is an existing collection of approximately 600 accessions of climbing beans collected from all the bean production regions in Guatemala. This collection is kept by ICTA and has been characterized morphologically, agronomically, and with 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

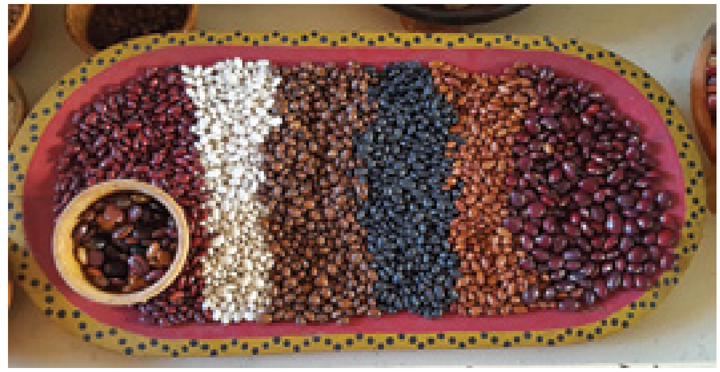
Technical Research Progress

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

1.1. Farmers' 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 (different 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. Selected superior lines could be released as varieties in the near future while a breeding pipeline is established. The trials were planted in May and grown at the ICTA-Quetzaltenango station and ICTA-Chimaltenango in 2015. In addition, an evaluation for natural infestation of *Asphondylia* sp. was also made at ICTA-Chimaltenango. In general, all genotypes were affected by this insect; however Texel was the least affected and the highest yielding of the genotypes.



A selection of the many different kinds of climbing beans grown in Guatemala's western highlands

1.2. Breeding pipeline
With the results obtained from the field testing and the evaluation of the germplasm collection during the 2014 growing season, a first set of 23 potential parents were selected by Osorno, Villatoro, McClean, and Aldana, and planted in the greenhouse at the ICTA station in Chimaltenango during the 2015 growing season. Parental accessions were selected mainly based on uniform pod distribution, potential yield, and disease resistance.

Unfortunately, the first generation of single crosses during FY 15 encountered difficulties in regard to flowering synchronicity in spite of the material being planted at staggered dates. We tried these crosses again in FY 16 and also attempted crosses in the field rather than in the greenhouse to save time. By doing this, we successfully obtained 36 F1 populations. All the F1 seed was then planted in the field at ICTA-Quetzaltenango during the 2016 growing season for evaluation and generation advancement. An additional 71 crosses were also made during the 2016 growing season at ICTA-Chimaltenango and are currently being harvested to create a continuous breeding pipeline for the future.

> ***Unfortunately, on-farm productivity of climbing beans is approximately one-third of its genetic yield potential, mostly due to the lack of improved cultivars able to withstand biotic and abiotic stresses.***

1.3: 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 because he kept these lines as bulked lines during multiple generations. Consequently, no individual plant selections were made during the breeding process; however, individual plant selections

have been made within these breeding lines since 2013. An initial set of 101 F7 and 29 F5 individual plant selections have been 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 in 2015-2016 and each selection was planted as individual rows for further evaluation/selection. This allowed for detection of additional genetic heterogeneity within lines while increasing seed. Since phenotypic heterogeneity was still detected, 97 individual plants from different F8 lines and 19 F6 lines were selected and sent to ICTA-Quetzaltenango for evaluations during the 2016 growing season. All these lines have been selected based on the characteristics mentioned above and harvest of this material is almost complete.

1.4. Field evaluation of the three most promising genotypes (Bolonillo-TEXEL, Utatlan, and Labor Ovalle (ICTA))
Validation plots were made in farmers' fields for the three genotypes that demonstrated the best potential as new improved cultivars: *Bolonillo-Texel, Utatlan*, and *Labor Ovalle*. These validation plots were planted side-by-side against the local landraces normally grown by the farmers across 15 locations distributed in Quetzaltenango, San Marcos, and Totonicapan. Across locations, Labor Ovalle (table 1) showed the greatest difference between the improved genotype and the local check, followed by Texel. After the 2016 growing season, final decisions will be made to decide which genotypes will be officially released as new climbing bean varieties for the Guatemalan highlands.

Charting the bean plant growth and development in a field trial

Since these trials are mostly managed by growers, data collection is focused on seed yield, agronomic performance, and personal feedback. Results from 2016 will allow the collection of enough data across years and locations for the validation group to present this as an official release at ICTA.

Differences in pod color have been noticed in these trials that confirm the genetic heterogeneity still present in Bolonillo Texel. Although not an issue for local growers, the genetic heterogeneity does concern the breeding team, which is working to develop a uniform variety by the project's end. Because the MASFRIJOL project is also very interested in obtaining a new climbing bean variety for its dissemination program, efforts are being coordinated to accelerate the process.

Genotype	Seed Yield (Kg/Ha)	Seed Yield of Local Check (Kg/Ha)	Yield Difference (Kg/Ha)
Utatlan	262	221	41^{NS}
Labor Ovalle	407	235	172*
Texel	506	359	148*
Mean – All Genotypes	391	271	120*

Table 1. Seed yield of three improved genotypes of the ICTA climbing bean project across 15 locations during the 2015 growing season.
*Significant differences ($P<0.05$) based on paired t-test

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)
Work on this objective began with very promising results. The original Guatemalan climbing bean collection had 594 accessions. After selecting the accessions with seeds with uniform color, shape, and size, the number of accessions was reduced to 377 to remove segregation and to ensure consistency in the population structure analysis and the association mapping study. The intra-accession diversity of the collection will be evaluated in a different step of this study.

Methods

- 377 accessions of *P. vulgaris* collected in the highlands of Guatemala 50 years ago were analyzed.
- Two seeds of each landrace were planted; tissue was collected 15 days after planting.
- DNA extraction was made using the Genomic DNA Mini Kit (Plant), from IBI SCIENTIFIC.

Lab tests of improved varieties

For association mapping, SNP markers with minor allele frequency ≥ five percent (78,754 SNPs) were used and Principal Component Analysis (PCA) was used to control for population structure.

- The libraries were created using Genotype by Sequencing and then sequenced using Illumina platform.
- Reads were mapped to version 2 of the G19833 reference genome sequence using BWA-MEM.
- SNPs were called using the Genome Analysis toolkit – GATK; 102,822 SNPs were obtained.
- Using the markers, a maximum-likelihood tree was developed using SNPhylo. Markers were selected by using a Linkage Disequilibrium (LD) cut-off value of 0.1.
- Population structure was analysed using fastSTRUCTURE, with K=1 to 10. The best K was determined using the model complexity that maximizes marginal likelihood and *Distruct* (a program from the Rosenberg lab at Stanford University that can be used to graphically display results produced by the genetic clustering program *Structure* or by other similar programs) was used to generate the plots.
- For association mapping, SNP markers with minor allele frequency ≥ five percent (78,754 SNPs) were used and Principal Component Analysis (PCA) was used to control for population structure.
    - Two PCs cumulatively explain 12 percent of the variation.
- A kinship matrix, generated by EMMA algorithm, was used to control for individual relatedness.
- The traits evaluated for Genome-Wide Association Study (GWAS) were 26, using the morphological characterization performed on this collection with GAPIT. Multiple models were tested for each trait: ***Naive*** model, ***Linear*** model with fixed effect to account for population structure, ***Mixed linear*** model to control for relatedness or relatedness and population structure.
- The best model was determined using the Mean Square Differences (MSD); markers with a bootstrapped (1,000 replications) p-value falling in the top 0.01 percentile were considered as significant levels.

A field of climbing beans at the ICTA Chimaltenango station

Preliminary Results

The estimated number of subpopulations was nine, based on the model complexity that maximizes marginal likelihood. Figure 2 shows the individual distribution for each population. However, based on the ML tree (figure 1) and the PCA analysis (figure 3), the population structure is low. A total of 101 accessions had a value of membership greater than 0.8 in the nine populations. The analysis also shows a high percentage of admixture in the accessions. Researchers concluded that the high number of markers used for this analysis allowed a false determination of K using STRUCTURE. It has been suggested that Guatemalan climbing beans belong to *race Guatemala*, which explains why the accessions are so similar between them. A comparison with accessions of Mesoamerican and Andean races will allow the confirmation of this hypothesis and will be the next step in this study. Additionally, a comparison with a new set of Guatemalan climbing bean accessions (500) collected in 2015 will be compared to this group to determine their geographical location.

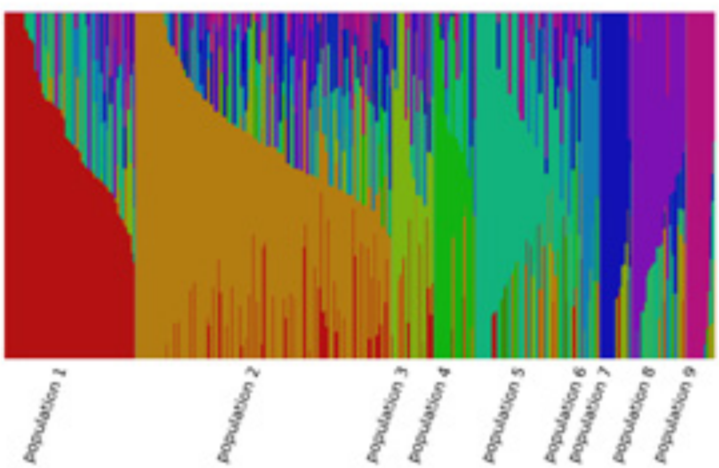


Figure 2. Hierarchical organization of the 369 climbing bean accessions based on 2732 SNPs (LD=0.1) for K=9.

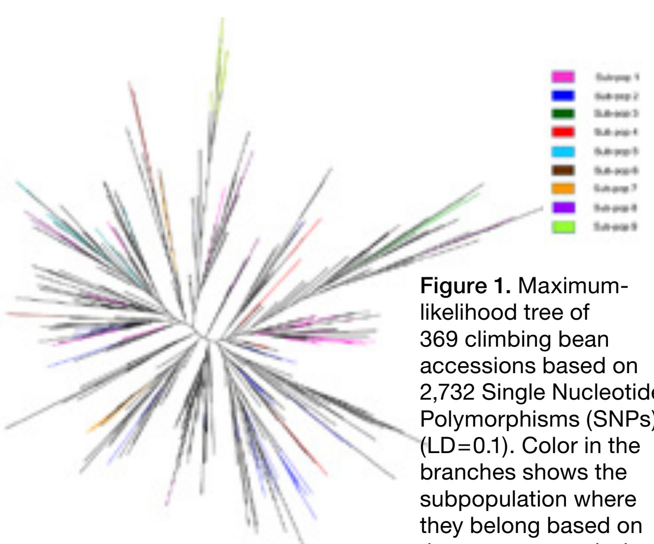


Figure 1. Maximum-likelihood tree of 369 climbing bean accessions based on 2,732 Single Nucleotide Polymorphisms (SNPs) (LD=0.1). Color in the branches shows the subpopulation where they belong based on the structure analysis.

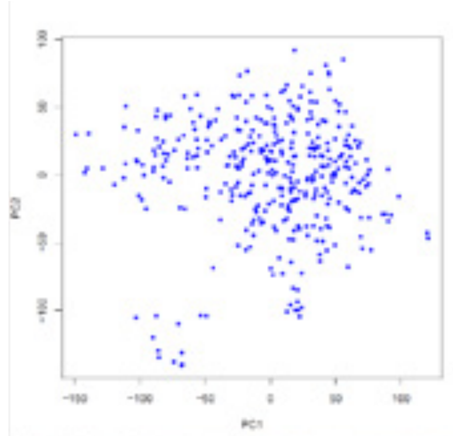


Figure 3. Principal Component Analysis (PCA) of the SNPs diversity for the Guatemalan climbing bean accessions.

A GWAS analysis was performed for multiple traits (agronomic and natural disease pressure) using phenotypic data previously recorded under field conditions at ICTA-Chimaltenango. Such genomic information can help the development of good resistant cultivars in the future. For Rust resistance, a significant peak in chromosome 2 (figure 4) was found; this SNP is inside a gene encoding a leucine-rich repeat transmembrane protein kinase. This type of gene is generally associated with plant resistance to diseases. For downy mildew resistance, there is a strong peak found in chromosome 6. This marker is inside a gene encoding an ubiquitin ligase binding protein. Other studies relate this type of gene with resistance to necrotrophic pathogens. Results such as these are promising for the use of this collection as a source of alleles in common bean breeding.

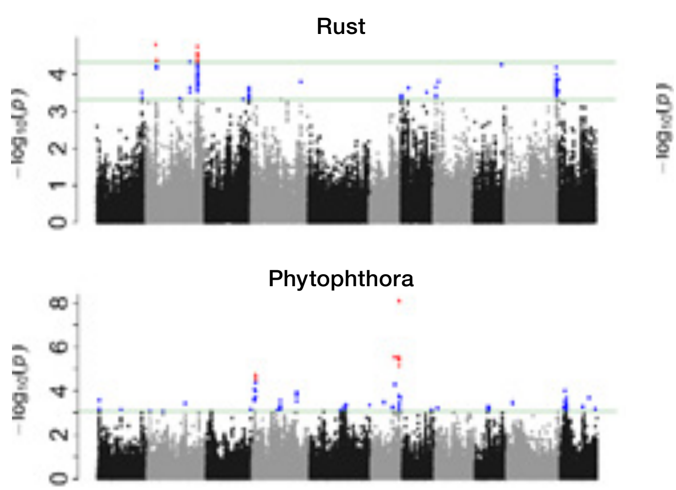


Figure 4. Manhattan plots of the best models for Rust and *Phytophthora* resistance. The green lines are the cut-off values to call a peak significant. The SNPs that pass the 0.01 percentile are highlighted in red, while those that pass the 0.1 percentile are highlighted in blue.

Bean samples containing rust were collected from bean producing fields in the Guatemalan highlands, which led to the identification of two frequently occurring rust races, identified here as 63-1 and 31-1. Samples were taken from Chimaltenango, Quetzaltenango, and San Marcos during the end of the 2015 growing season. Both races were found within each department; preliminary results suggest that they affect mainly Andean-origin rust genes. In addition, the entire climbing collection was screened for those two Guatemalan rust races and for race 20-3, the newest and most frequent race in North Dakota. Preliminary results indicate that 39 percent of the climbing bean accessions show resistance to 63-1 and 58 percent to 31-1. Resistance to the ND rust race, 20-3, is currently being evaluated at NDSU.

In the case of Anthracnose, the climbing bean collection was evaluated with race 73, which is the most commonly found race in North Dakota. Preliminary results suggest that almost 10 percent of the climbing bean germplasm accessions are resistant to race 73. Anthracnose sampling of climbing beans was made from leaves, pods, or stems that showed symptoms of anthracnose from small-scale farmers' fields in Totonicapan, Quetzaltenango, San Marcos, and Huehuetenango during the 2015 and 2016 growing seasons. These samples will undergo further race typing and characterization.

All phenotypic data collected from disease reaction to rust and anthracnose will be used to identify genomic regions associated with genetic resistance using the same GWAS approach noted above. Results will be useful not only for Guatemala but also to find new potential sources of resistance to local races in North Dakota. Once genomic regions are located, new diagnostic markers can be designed for use in a Marker Assisted Selection (MAS) scheme.


Climbing beans maturing in a field in Guatemala's western highlands

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

In March 2015, a survey was conducted among bean growing farmers in Quiche, Huehuetenango, San Marcos, Totonicapán, and Quetzaltenango—the five Guatemala departments that represent most of the climbing bean production areas.

Major findings are summarized below.

Bean Consumption

- The majority of farmers (80 percent) do not sell beans; only six percent sold more than 50 percent of their harvest.
- Self-produced beans covered less than half of annual bean consumption for 23 percent of farmers; self-produced beans covered between 50-75 percent of annual consumption for 33 percent of farmers. After self-produced beans were consumed, 50 percent of farmers purchased beans at least weekly.
- On average, a household cooked beans 2.5 times and consumed a total of five cups of (uncooked) beans in the week prior to the survey.

Beans are consumed throughout the year; consumption is highest at or after the harvest—from November to March—and lowest in July and August.

- On average, households with children under 14 served beans to the children on three days in the week preceding the interview. On days that children ate beans, more households served beans at breakfast (75 percent) and dinner (79 percent) than at lunch (53 percent).
- Beans are consumed throughout the year; consumption is highest at or after the harvest—from November to March—and lowest in July and August.
- Dietary diversity, culinary preferences, and farmers' perceived nutritional value of beans were assessed.
- On average a household consumed six out of 12 diverse food groups in the day prior to the survey; more than 85 percent reported consuming beans the previous day.
- *Frijol negro, vulgaris,* and *bolonillo* were among the most preferred bean varieties for consumption named by farmers.
- Respondents indicated that flavor (76 percent) was what they like most about a bean variety, followed by thickness of bean broth (32 percent), cooking time (3.2 percent), expansion of size (1.5 percent), and color retention during cooking (0.7 percent).
- On a scale of 0-10, farmers rated beans 8.9 in nutritional value, just below the score for maize (9.4) but higher than the perceived nutritional value of rice (8.1), potatoes (7.8), meat (6.9), chayote (5.9), and Coca-Cola (1.4).

Bean Productivity and Production Practices

- An average household owns 0.73 ha and devotes 1.3 parcels of land on the simultaneous planting of the milpa system, with an average plot size of 0.29 ha. The average bean yield on the simultaneous planting milpa plots is 318 kg/ha.
- Farmers use the milpa intercropping system with low crop rotation. The majority of farmers' plots were planted with maize in the year of the survey (94 percent) and also in the previous year (92 percent). Climbing beans were also planted on the same plot in the previous year (91 percent).
- Simultaneous milpa was a more common practice than waiting several weeks to plant beans (relay) (21 percent); only 2.3 percent of plots surveyed had beans planted alone in rows or intercropped with other crops.
- Most plots were planted with one bean variety (74 percent), while 18 percent had two varieties, and 6 percent had three varieties.
- Desired characteristics of a bean variety as cited by farmers are yield (49 percent), seed size (36 percent), seed color (32 percent), fast cooking time (32 percent), taste (31 percent), resistance to field pests (27 percent), resistance to lodging/weighing down maize (23 percent), early maturity (21 percent), and resistance to diseases (21 percent).
- Farmers are willing to pay on average $6.6 Guatemalan Quetzals per pound (US$ 0.80) for improved variety seeds with the characteristics they desire and indicated that they would initially purchase on average 6.8 pounds of seed.

The study is one of the first representative farm surveys of climbing bean growers in the region. Analysis of the data has yielded a better understanding of farmer characteristics, bean production practices in the milpa system, and the role of beans in household food consumption. Overall, it contributes toward establishing priorities for the climbing bean breeding program aimed at increasing productivity within the milpa system.

3.2. Seed increase of samples collected during the survey (ICTA/NDSU)

During the survey, seed samples were requested from each farmer surveyed; about 85 percent of the growers complied, giving us a set of approximately 460 climbing bean germplasm accessions that mostly represent the diversity of climbing bean lines currently being planted. Among these are 100 accessions collected by the ICTA genetic resources unit in 2015. Four seeds from each were planted in the greenhouse in 2015 for increase and future evaluation during FY 2016. Harvested seed from the greenhouse was then planted in the field for a second round of increase and evaluation at ICTA-Chimaltenango during the 2016 growing season; it was being harvested at the time of this report. This collection provides an opportunity to conduct a phenotypic evaluation of the germplasm collected and, possibly, to identify genetic material of interest for the breeding pipeline. A group of 24 accessions from this new germplasm group have been selected in the field at ICTA-Chimaltenango for future testing and crosses.

Future activities with this set of germplasm include a comparison of the original germplasm collection from ICTA with this new collection for changes in genetic diversity across time. Seed samples have been received at NDSU, and DNA extraction is currently under way. Because the location of each seed sample is available, some geographical diversity analyses are possible. This new germplasm could also be compared with the original germplasm collection via SNP analysis to establish genetic similarities and to pinpoint a possible geographical origin for the original germplasm collection.

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

4.1. Graduate Students

Recruiting efforts during FY 2014 and FY 2015 at ICTA have identified three MS candidates at NDSU. Their research topics are directly related to project research objectives, described above. The students began their study programs in the fall of 2015. More information can be found, below.

4.2. Site visit/workshop at NDSU for ICTA personnel

Six host country collaborators spent seven days during July 2016 at NDSU to learn how beans are produced in North Dakota and to receive training on modern techniques in plant breeding, plant pathology, molecular markers, and other genomic tools connected to the breeding process.

Members of the Guatemalan bean team examining improved climbing bean plantings in San Jeronimo, Guatemala

Major Achievements

1. On-farm testing and validation of Bolonillo-Texel, Utatlan, and Labor Ovalle across 15 locations.
2. Initial molecular characterization (DNA extraction) of climbing bean collection.

3. Completion of bean growers' survey with identification of key characteristics to guide research priorities.
4. Selection of new genotypes with breeding potential from samples collected during growers' survey.

Human Resource and Institutional Capacity Development

Long-Term Training

Three students (two females and one male) began their MS program at NDSU in fall 2015 and have been progressing in their study programs. These students were selected by the PIs and ICTA in Guatemala for further training. They are all seeking MS degrees in Plant Sciences, focusing on bean breeding and genetics.

A local Guatemalan farmer talks about the impact of planting improved varieties of climbing beans in his village.

	Date	Male	Female	Total
1	10/6/2016	40	10	50
2	10/12/2016	11	5	16
3	10/13/2016	129	73	202
4	10/18/2016	52	65	117
5	10/19/2016	47	76	123
6	10/21/2016	36	4	40
7	10/23/2016	31	3	34
9	10/25/2016	123	82	205
10	10/28/2016	64	17	81
	Total	**533**	**335**	**868**

Table 2. Participation in Field Days at ICTA-Quetzaltenango.

Short-Term Training

A site visit/workshop to train a group of six host country scientists (three female, three male) in modern plant breeding techniques and bean production systems in the United States was held at North Dakota State University in Fargo, North Dakota, July 17–24, 2016. ICTA-Guatemala and Zamorano-Honduras benefitted from this training.

A series of one-day workshops was held at ICTA-Quetzaltenango, Guatemala, from October 6-28 for 335 females and 533 males (a different group each day) to learn about different aspects of crop production, including bean and maize. Guatemalan farmers benefitted from this training. See table 2.

Research Capacity Strengthening Funding

LIL institutional capacity strengthening 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 on crop and animal production research. Project researchers participated with more than 400 other scientists sharing research and innovations in agriculture throughout the region.

Achievement of Gender Equity Goals

An effort has been made to identify excellent female candidates for training, field, and laboratory work at ICTA. The ICTA bean breeding program includes two women on their team who are in charge of the activities at San Jeronimo and Quetzaltenango. Additionally, two women ICTA employees have been recruited for formal MS degree training in plant sciences at NDSU.

Scholarly Accomplishments

Osorno, J. M., McClean, P., Villatoro, J. C., Aldana, L. F., Moscoso-Alfaro, J., Montejo L. M., Maldonado, C., & Tobar, M. G. (2016). Breeding efforts for the improvement of climbing beans for the Guatemala highlands. Pan-African Grain Legume and World Cowpea Conference. Livingstone, Zambia. February 28 to March 4.

Osorno, J. M., Villatoro, J. C., Miranda, A., & Moscoso-Alfaro, J. (2016). Climbing beans affected by *Ascochyta spp.* in the Guatemala highlands. IV International Ascochyta Workshop. Troia, Portugal. October 10-11.

Villatoro, J. C., Moscoso-Alfaro, J., Agreda, K.A., Osorno, J. M., McClean, P., & Montejo, L.M. (2016). Preliminary study of the presence, damage level and population dynamics of Mexican pod weevil (*Apion godmani*) in bean genotypes (*Phaseolus vulgaris*), in the highlands of Guatemala. Pan-African Grain Legume and World Cowpea Conference. Livingstone, Zambia. February 28 to March 4.

Villatoro, J. C., Osorno, J. M., McClean, P., Aldana, L.F., Moscoso-Alfaro, J., Miranda, A., & Agreda, K.A., (2016). Evaluación de genotipos de frijol voluble, densidades, y su efecto sobre el maíz. Annual Mtg. PCCMCA. San Jose, Costa Rica. May 5-8.

A project technician uses the MultispeQ to test for phenotypes on a common bean plant in Zambia.

Improving Photosynthesis in Grain Legumes with New Plant Phenotyping Technologies

(SO1.A2)

LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

David M. Kramer, Michigan State University

COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

Kelvin Kamfwa, University of Zambia

Kennedy Muimui, ZARI, Zambia

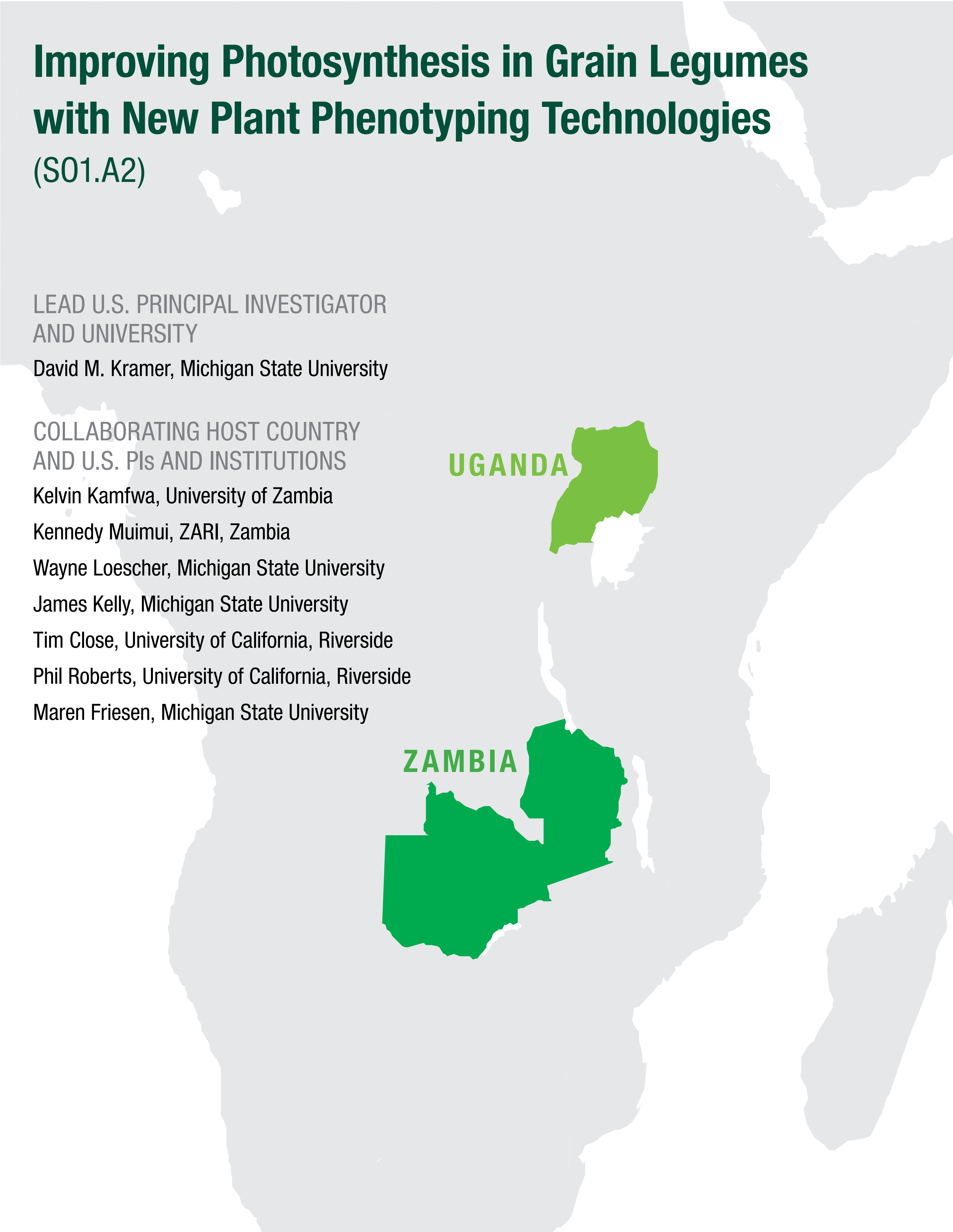
Wayne Loescher, Michigan State University

James Kelly, Michigan State University

Tim Close, University of California, Riverside

Phil Roberts, University of California, Riverside

Maren Friesen, Michigan State University



Abstract of Research and Capacity Strengthening Achievements

In FY 2016, substantial progress was made on all project objectives. A key component of this progress was the development, dissemination, and application of phenotyping technologies to partners to identify target processes and genes for improvement of photosynthetic responses in beans and cowpeas.

There are two major components to the project: bringing the lab to the world, through an open access science platform, *PhotosynQ*, that brings cutting-edge phenotyping and analytics technologies to field researchers around the world, and bringing the world to the lab. The latter occurs when *PhotosynQ* users upload their data from the *MultispeQ*, which can then be accessed by plant scientists throughout the world, who can use it to complement textbook learning or expand research projects beyond the confines of their own geographic areas and labs.

An engineer in Dr. Kramer's lab examines the MultispeQ as part of its ongoing development.

A publication describing the development, characterization, and initial use of the MultispeQ has just been published. We delivered six MultispeQ beta devices to the University of Zambia (UNZA) and are following up with a set of the newly released version of the device. We also trained seven undergraduate students at UNZA and two research technicians at the Zambia Agricultural Research Institute (ZARI), who collected quality field measurements of common bean GWAS (Genome-Wide Association Study) lines for QTL (quantitative trait loci) mapping. Based on initial results from our collaboration with UNZA, the project has revised the MultispeQ, developed new protocols and procedures to improve the statistical sampling of phenotype data, and developed analytical methods to process complex interactions among photosynthetic and environmental parameters. In a major achievement, UNZA has produced a complete proof-of-concept GWAS mapping for photosynthetic responses of common beans to drought using the PhotosynQ platform.

Project Problem Statement and Justification

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

> *There are two major components to the project: bringing the lab to the world, through an open access science platform, PhotosynQ, and bringing the world to the lab.*

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

Our approach has been to harness the two recently developed phenotyping technologies—the Dynamic Environmental Phenotyping Imager (DEPI) and the PhotosynQ platform, a field-deployable network of handheld sensors (MultiSpeQ) and associated on-line communication and analysis tools.

Objectives

1. Probing photosynthetic responses in RIL and GWAS lines.
2. Increasing 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.
3. Developing a Data Management Plan

Technical Research Progress

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

During the past year, the primary focus toward this objective was to build high-throughput methodologies for QTL mapping using the DEPI platform. To accomplish this objective, a range of developmental times for common bean GWAS genotypes was tested. Using the growth populations that we established for QTL mapping, the project successfully collected robust field measurements of photosynthesis in Zambia that were used for QTL mapping.

Taking photosynthesis readings using the MultiSpec and PhotosynQ—in the field and under controlled conditions.

At MSU, the project successfully mapped key QTLs using controlled conditions using the DEPI chambers, demonstrating the approach for distinguishing genetic variation in the responses of photosynthesis to both low and high temperatures. From these results, it has been determined which conditions and MAGIC (Multiparent Advanced Generation Inter-Cross) populations are best suited for QTL mapping for photosynthetic responses to temperature; the experimental protocols are in the process of being performed and analyzed.

Objective 2. Increasing 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.

In December 2015, we distributed six MultispeQ instruments and six android mobile devices to the University of Zambia and Dr. Kelvin Kamfwa, who completed his doctoral training at MSU in 2015 and works at the University of Zambia, and trained six undergraduate students on the MultispeQ and the PhotosynQ platform. Students then began collecting PhotosynQ data. In March 2016, David Kramer and Dan TerAvest visited UNZA and trained undergraduates on data collection methodologies and the plant physiological parameters measured by the MultispeQ instrument. Students at UNZA have now collected more than 4,000 MultispeQ measurements on the common bean Andean Diversity Panel.

Concurrently, Isaac Dramadri, a graduate student from Uganda, continued to use PhotosynQ to probe the photosynthetic responses of RIL and GWAS lines at MSU. At the end of FY 2016, Dramadri returned to Makerere University in Uganda, where he will train faculty and staff on the PhotosynQ platform.

Objective 3. Developing a Data Management Plan

As a part of the development process, we will modify the PhotosynQ platform to meet the needs of project collaborators while concurrently meeting the requirements of USAID's open data policy. The project is currently in the process of working with USAID staff to ensure that the PhotosynQ platform conforms to USAID policies.

Major Achievements

1. Dissemination and publication of the PhotosynQ beta instrument
2. First proofs-of-concept for the complete QTL mapping process for photosynthetic properties in common beans using PhotosynQ at the University of Zambia
3. Training of several graduate students at both UNZA and MSU on the PhotosynQ process
4. Development of new PhotosynQ-guided experimental protocols

Kelvin Kampfa, one of the project's lead researchers in Zambia, examines bean plants.

Research Capacity Strengthening

Several LIL research scientists from other LIL projects are using the PhotosynQ platform as part of their LIL-supported work.

The project is actively working toward establishing cutting-edge phenotyping centers at the University of Zambia and Makerere University in Uganda. At UNZA, faculty and staff now have access to six MultispeQs and are actively involving the UNZA team in the redesign, validation, and implementation of the new version 1.0 devices and the new online analytical capacity, both of which will lead to publications and help form a phenotyping center at UNZA.

In addition, eight students at UNZA and two research technicians from Zambia Agricultural Research Institute (ZARI) in the Ministry of Agriculture have received training on PhotosynQ. Additionally, there are three MultispeQ instruments available for faculty and staff to use at Makerere University, which led to the creation of four separate research projects for which nearly 7,000 measurements have been made on cowpea, groundnuts, and maize.

The irrigation system at the research station at UNZA is currently being renovated and upgraded using supplemental Institutional Capacity Strengthening funds. Purchase of irrigation equipment and renovation works are under way. Once the renovations are complete, UNZA's capacity to conduct drought experiments in FY17 will be enhanced.

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

Achievement of Gender Equity Goals

A critical component of accomplishing gender equality goals is to ensure that PhotosynQ technologies are equally accessible to women and men. In FY 2016, we made progress toward that goal by training two female undergraduate students at UNZA and identifying a female graduate student who will pursue a master's degree in plant breeding and seed systems at UNZA using the PhotosynQ platform beginning in FY 2017.

Using the MultispeQ, a project technician tests for phenotypes on a common bean plant in Zambia.

Project team members scan bean plants with the MultispeQ to determine phenotypes in the bean plants they want to breed for biotic and abiotic improvements.

Scholarly Accomplishments

Kuhlgert, S. et al. (2016). MultispeQ Beta: A tool for large-scale plant phenotyping connected to the open PhotosynQ network. *R. Soc. open sci*. 3: 160592. http://dx.doi.org/10.1098/rsos.160592.

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U.S. and host country collaborators pose in a bean field in Uganda.

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 and Capacity Strengthening Achievements

Common bean is the most important grain legume consumed in Uganda and Zambia. The project has successfully identified local lines that are faster cooking for testing in on-farm trials in Uganda. Host country breeding programs continue to identify sources of disease resistance to the more serious pathogens that attack beans and are using these lines as parental material to further improve local varieties.

Climate change is leading to less predictable rainfall patterns, but the project has identified Andean breeding lines that perform better than local varieties under these conditions. Novel methodologies are being developed to screen for cooking time more efficiently, and modern molecular tools have been deployed to map genomic regions that control anthracnose resistance. Genomic mapping with SNP markers and RNA sequencing has been used to pinpoint genomic regions that control anthracnose resistance and enhanced symbiotic nitrogen fixation; the candidate genes underlying these basis functions have been identified. The potential to enhance N-fixation in beans grown under low fertility conditions typical of subsistence farmers is now within the reach of local breeders. Training of future bean researchers continues to develop scientific and leadership skills.

Project Problem Statement and Justification

Zambia

Beans are the second most important food legume crop 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, mainly, with maize.

> *The majority of bean production in Uganda depends, however, on inferior landrace varieties that are generally low yielding due to susceptibility to the major biotic and abiotic stresses.*

Bean production is constrained by several abiotic and biotic stresses that include diseases, pests, low soil fertility, and drought. All the popular local landraces in Zambia are highly susceptible to pests and diseases that severely limit their productivity. This is reflected in the very low national yields ranging from 300 to 500 kg/ha that result in an annual deficit of 5,000MT.

To avert future food shortages and feed the growing population of 13M, there is critical need for increasing the productivity of most food crops, including beans.

A poster highlighting the many different kinds of beans grown in Zambia

Uganda

Grown on more than 660,000 ha of land, beans are a major source of food throughout Uganda, providing a large percentage of income for smallholder farmers, especially women and children. The majority of bean production in Uganda depends, however, on inferior landrace varieties that are generally low yielding due to susceptibility to the major biotic and abiotic stresses, which gravely undermine the bean's potential 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 are 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 BNF, 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 to 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 MAS 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 to 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 2016, the research project in Uganda continued to assemble and utilize different nurseries, which included the following: 50 lines (50 seeds each) for common bacterial blight (CBB), a drought nursery of 60 entries (500 seeds each), a set of 10 lines for Rust, and a drought nursery of 96 Andean (DAB)-lines.

These nurseries have been evaluated; those showing resistant potential have been used in breeding programs for introgression of specific resistances into susceptible Ugandan germplasm.

1.2 Evaluation of Integrated Nursery in Zambia

In Zambia a traditional breeding approach was undertaken to combine resistances for angular leaf spot (ALS) and CBB into preferred seed types at Misamfu. The resulting lines were evaluated in other Zambian sites where bean production is important. After a number of selection cycles, 50 lines were selected and planted at three in-country sites. Of the 50 lines planted, 28 lines were selected at Misamfu, 23 in Kabwe, and 21 at Msekera; 11 were common at all three sites. These same lines have been earmarked for on-farm testing. Most of the lines selected were medium- to large-seeded as preferred by smallholder farmers in Zambia. The lines were also resistance to ALS and CBB.

1.3 Identification of resistance sources in Uganda

A disease nursery was screened against different pathogens, rust, anthracnose (ANT), and ALS in a screenhouse and under field conditions in Uganda. Using field conditions for prevailing diseases and/or screenhouse conditions with inoculum from different pathogens, a number of nurseries and/or germplasm sets were screened using different pathotypes for different pathogens, from which the reaction of different germplasm to the different pathogens was established along with the identification of some resistant genotypes used to introgress resistances to susceptible but preferred market class varieties for Uganda.

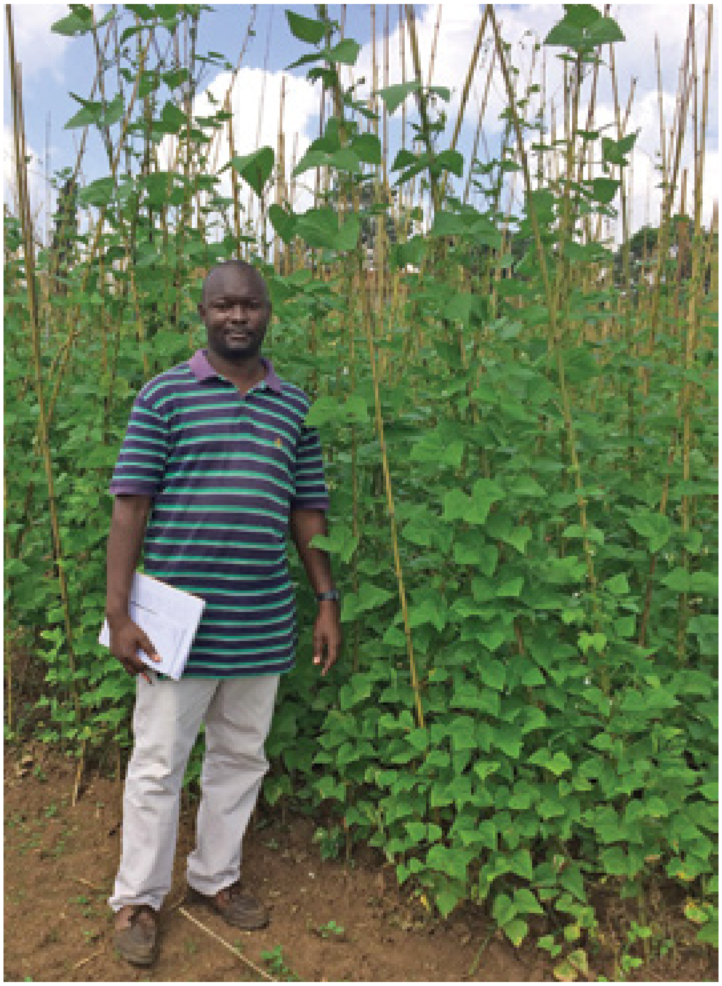
A germplasm collection of 132 common bean accessions was screened in both screenhouse and field for reaction to CBB. Another assembled germplasm collection of 80 lines from CIAT and local germplasm was screened for resistance to BCMV. Lines selected for resistance to rust include *Mexico 309, CNC, P1181996, Mexico 235, Redlands Pioneer, Ouro Negro,* and *Aurora*; Selected resistant lines that are resistant to CBB include *NE2-14-8, NE17-14-29, NE14-09-78*, and *VAX3*; Selected resistant lines that are resistant to BCMV include *SCR 48, SCN 9*, and *SCN 6*.

1.4. Cross sources of resistance for ANT, ALS, CBB, rust

> ***For all the resistant genotypes that have been identified for the various pathogens, crosses have been initiated with Uganda market class and consumer preferred varieties to introgress resistant genes for respective traits.***

and drought tolerance into large seeded lines with contrasting colors in Uganda

The project has continued to introgress different resistance genes into the backgrounds of some of the most preferred Andean bean varieties in Uganda. For all the resistant genotypes that have been identified for the various pathogens, crosses have been initiated with Uganda market class and consumer preferred varieties to introgress resistant genes for respective traits. We have also started generating population for the new crosses that include populations for rust, CBB resistance, and BCMV resistance. The progenies are under evaluation. Genetic studies have been undertaken to determine the mode and nature of inheritance for CBB resistance.



A researcher studies a field of improved varieites.

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 *K132, NABE 4* and *NABE 15* with introduced drought tolerant. Nine promising lines from nine different crosses have been selected and are currently undergoing preliminary yield trials on-station at NaCRRI.

1.5. Cross lines with superior disease resistance to those with shorter cooking time and high mineral bioavailability

The initial 23 ADP lines that were selected for shorter cooking time were tested for adaptability, preference, and fast cooking time with nine farmer groups composed of 326 farmers (96 men and 230 women) in three agroecologies in Uganda. From these, seven lines have been identified as suitable and having shorter cooking times.

1.6. Drought tolerance

The ADP panel of 250 genotypes was planted during May–August to use genomic and phenometric tools for improving selection and breeding for drought tolerance in the large seeded bean. The field experiment consisted of two treatments—irrigated and nonirrigated—in two replications planted in the field at NaCCRI. During May to August, NaCRRI received unusually high rainfall and no drought stress was observed. These moist conditions, however, led to multiple disease conditions, and data was collected on all agronomic traits and such major common bean diseases as ALS, Rust, CBB, and BMCV.

A nursery of 60 bean lines from the University of Nebraska (UNL) was screened under terminal drought protocol during the off-season period and irrigation was employed. Preliminary results identified seven lines performing fairly well in drought conditions that could be suitable varieties for utilization in drought prone and semi-arid regions of Uganda and, potentially, good sources for drought-tolerant genes for breeding.

A second preliminary yield trail was conducted for 169 lines from CIAT to confirm first trial data and increase seed for multilocation yield trials. Results indicate yield variation with a range of 3,625 kg. This large variation in yield between different genotypes will be exploited to select and utilize best adapted and highest yielders for future release and utilization in the breeding program.

In another germplasm evaluation trial, 421 individual plants that were selected from 35 segregating drought large-seeded bean populations obtained from South Africa and established in trials as 421 single row families and evaluated. From these trials, 416 lines were selected (only five lines deselected) due to superior performance exhibited by the families. Selections were mainly based on early maturity and market trait characteristics. Further selection will be basing on yield, disease resistance, and drought tolerance.

A 25-entry uniform drought nursery was grown in Michigan. Weather conditions were favorable for the development of drought in the first 45 days following nursery establishment and the local check varieties outyielded most of the drought tolerant lines, underscoring the importance of local adaptation.

1.7. Nebraska

The common bacterial blight nursery dispatched to Uganda and Zambia was screened for CBB reaction in North Platte, Nebraska, in an augmented replicated field trial. At flowering, plants were sprayed with a bacterial solution and the lines were evaluated at the pod filling stage. Data are being analyzed. The ADP lines were tested for response to terminal drought, with irrigation stopped at flowering. Data are being processed. The drought tolerant lines (ADP) dispatched to Uganda and Zambia were tested at both locations under normal and drought conditions.


A farmer co-op group.

1.8 Farmer Evaluation of the Nutritionally Superior Bean Genotypes in Three Agroecological Zones in Uganda

A subset of the ADP comprised of 23 genotypes representing various market classes and selected for faster cooking times and superior nutritional quality profiles was screened on-farm across three districts in Uganda in 2015. Farmers rated seed quality preferences after harvest. In general, they preferred high yielding, early-maturing lines that exhibited tolerance to too little and/or too much water. A small seeded red mottled variety (*Chijar*) from Puerto Rico was consistently the most productive across all the agroecological zones, with an average yield of 1,000 kg ha^{-1}.

In the 2016 growing season, the genotypes were planted to evaluate their performance during the short rainy season across the nine locations; only 15 experimental entries were planted along with the local check. The growers collected data on disease stress and agronomic data during harvest for all 16 accessions. Farmers rated the genotypes at harvest on yield and seed quality. The most preferred genotypes were also evaluated for sensory quality in the communities. The seeds of genotypes from all accessions are being evaluated for cooking time, mineral profiles, and iron bioavailability to determine the stability of these traits and identify good germplasm for breeding to improve common bean for nutritional quality traits.

1.9 Crossing resistance sources in Zambia

A common bacterial blight nursery of 50 lines was planted and evaluated in Misamfu and Mpika, Zambia. More than 66 percent of the lines showed some level of resistance to CBB and were evaluated for ANT and ALS. The light red kidney variety *Badillo*, which is resistant to CBB, high yielding, and well adapted to Zambia, was crossed with the local landrace *Kabulangeti*, which is susceptible to CBB. The F4 population of the cross was planted in the field in the 2016 growing season for seed multiplication and evaluation during the 2016-17 season.

"The growers collected data on disease stress and agronomic data during harvest for all 16 accessions."

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

In 2015-2016, advances in cooking time prediction were made in the development and optimization of Vis/NIRS chemometric models, using dry bean seeds with broad genetic diversity and planted in different years and locations. In addition, a hyperspectral imaging (HYPERS) technique was implemented and tested for evaluating cooking time in similar accessions of dry seeds tested by Vis/NIRS.

1. Bean samples (446) from the ADP included accessions from Africa, Europe, Asia, Central America, Caribbean, North America, and South America; they were planted in Michigan in 2013.
2. Four different market classes among 140 bean samples from Eastern Africa, Southern Africa, the Caribbean, and North America were planted in 2014 over five locations in two contrasting geographical regions. Variations in cooking time ranged from 19.9 to 160.1 minutes.
3. Bean samples (113) were obtained from Washington and Tanzania and grown at the Montcalm Research Farm in 2015; cooking times for these samples ranged from 18.2 to 113.1 minutes.

1.11 Seed multiplication

In Uganda, bean lines were received for the different nurseries for maintenance and seed multiplication, with a few seeds planted in the screenhouse and in the field to evaluate for adaptability to local conditions and to make quick assessments on susceptibility to diseases.

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

Collections for different disease samples for different pathogens were collected, including 136 rust, 54 anthracnose, 24 BCMV, and 60 ALS samples from different bean growing agroecologies within Uganda that were isolated for further characterization.

Differentials for rust, ANT, and ALS were obtained and multiplied in the field to increase the amount of seed available.

The bean research group in Zambia.

Race characterizations of Rust, CBB, BCMV, ANT, and ALS were initiated in Uganda. A number of isolates were obtained from collected diseases samples for different pathogens; these were further characterized into different pathotypes using various techniques, indicated below.

A field survey was conducted in 15 Ugandan districts with areas of high bean production. High incidence of bean rust and severity was observed in the low altitudes and in the Western Highlands of Uganda.

Twenty-three single rust isolates were obtained from the diseases samples collected in Uganda and inoculated on 11 bean rust differentials and the *Ouro Negro (Ur-14 gene)* cultivar. From these isolates, six rust pathotypes were identified. *Mexico 309, CNC, P1181996, Mexico 235, Redland pioneer, Ouro Negro*, and *Aurora* were identified as having good levels of resistance to rust pathotypes in Uganda. A study was conducted to identify sources of broad-spectrum rust resistance in common bean germplasm including landraces, commercial cultivars, and introduced genotypes in Uganda. There were significant differences ($P < 0.001$) among the genotypes for disease incidence, AUDPC and total grain yield and a strong correlation ($P < 0.001$) between disease incidence and AUDPC. The SSR markers, *BARC_PV_SSR04725, bean_ssr_0778* and *bean_ssr_2892* were associated ($P \leq 0.05$) with rust resistance. Fifteen genotypes, which included the landraces *Nabufumbo* and *Kapchorwa white* and the commercial cultivar *NABE 2* were identified as new sources of rust resistance that would be useful in future bean breeding programs in Uganda.

Farmers and researchers pose together around one of the fields growing IVs being tested for drought tolerance.

Rust samples were sent and analyzed at the University of Nebraska. They indicated that *GN 1140 (Ur-7 gene)* was susceptible, but all other Middle American differentials were resistant (*Ur-3, Ur-5, Ur-3+, CNC,* and *Ur-11* genes). Additionally, all Andean gene sources with the exception of *PI 260418* and in a few instances *PC 50* and *Redlands Pioneer* were susceptible.

Information on foliar pathogens on the ADP and UNL drought-tolerant germplasm nurseries was obtained and leveraged for reaction to different foliar pathogens on surviving lines and in Uganda.

The CBB pathotype *Kawempe 1* was obtained and utilized to screen the available nursery and germplasm collection for resistant genotypes; four CBB resistant genotypes were obtained.

Eighty samples of BCMV were screened using inoculum obtained from the diseased plants in the field. Three genotypes were identified as resistant; these same genotypes are also tolerant to drought.

Information on foliar pathogens on the ADP and UNL drought-tolerant germplasm nurseries was obtained and leveraged for reaction to different foliar pathogens on surviving lines and in Uganda. We are now choosing the most relevant races of ANT, ALS, and rust and strains of CBB for screening breeding nurseries in Uganda. These same races will be utilized for the screening of progenies from the crosses that have been initiated.

Progress on incorporating Anthracnose (ANT) resistance is under way using the variety *Werna*, which is resistant to anthracnose and CBB. The F4 population of the cross between Kabulangeti and Werna was also planted in the field in the 2016 growing season for seed multiplication and evaluation for resistance.

Researcher Karen Cichy sorts through harvested beans with farmers in Uganda.

Six bean lines from the initial 405 entries from the ADP and NE trials previously screened in Zambia were found to have resistant to root and crown rots (RCR) and other foliar diseases and were adapted to Zambia. The primary pathogens associated with RCR were identified and characterized from samples collected in survival nursery trials evaluated in 2016.

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

Fast cooking lines with high mineral bioavailability grown in on-farm trials were evaluated for farmer acceptability based on agronomic and cooking characteristics. The initial 23 ADP fast cooking bean lines were reduced to 16 and re-evaluated with the same groups of farmers. Lines were then reduced to seven and taken through for sensory testing.

Sensory evaluation tests were conducted with nine famer groups in Uganda for the seven ADP lines' short cooking lines selected by the famers in the participatory variety selection trials.

New sources of anthracnose resistance in a highly diverse panel of 226 Andean beans were screened with eight races of anthracnose to identify and to map new sources of resistance using a genome-wide association study (GWAS) at MSU.

> *Drought stress also affects a number of photosynthesis related traits in beans.*

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. Work continues to develop Indel and SSR markers at the other genomic positions on Pv02, Pv04, Pv08, and Pv11 where resistance genes were identified.

An in-field irrigation system allows testing on drought-resistant varieties to be conducted even during the drought season because the irrigation system allows a comparison crop to be grown under normal conditions.

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

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. Research was conducted on the physiology of drought and heat stress in a selection of bean genotypes with varying degrees of stress tolerance, including tepary bean. The response of different metabolites to drought stress was a major focus. Beans exposed to drought stress had no differences in free proline concentration in their leaves, either between treatments or among genotypes. For soluble carbohydrates, no differences among genotypes were found under control conditions, but the concentration of malic acid, glucose, fructose, inositol, and raffinose all increased in the leaf tissues of plants exposed to drought stress. Glucose, fructose, and inositol were all found in higher concentrations in more tolerant genotypes, so it is likely that their accumulation is correlated with drought tolerance.

Grafting experiments revealed that shoot identity controls the concentration of ABA in root tissues under drought stress. Drought stress also affects a number of photosynthesis related traits in beans. Based on measurements of gas exchange on control and drought stressed beans, lower stomatal conductances are associated with drought tolerant genotypes regardless of water treatment. Lower stomatal conductances would allow a plant to conserve more water during periods of drought stress.

A market trader in Kampala, Uganda

Grafting experiments showed that stomatal conductance is controlled mainly by factors located in the shoot tissue and not the root tissue; however, these factors are unrelated to leaf density or the density of stomata on leaf surfaces. Bean plants exposed to temperatures of 45°C for two days showed measurable signs of heat stress. These measures also correlated well with visual signs of damage on leaf tissue caused by heat stress. Plant breeders can utilize some of these methods to supplement field data and further characterize the stress tolerance of later generation bean lines.

Objective 5. Institutional Capacity Building and Training

- Trained five technicians and four research assistants on drought screening and data capture, using the irrigation and nonirrigation technique.
- Five technicians, 326 farmers, and three personnel were taught bean disease identification and possible control measures.
- Farmers in Zambia, (118 males and 99 females) were trained in clean seed production and integrated pest and disease management for improved dry bean production and productivity. These seed grower associations help multiply and supply clean, reliable seed for more than 230,000 households growing beans in Zambia.
- Sixty-six students from six local agriculture training institutions were trained on RCR of dry beans and the methods of evaluation and sampling of plants for pathogen identification and integrated management of diseases and pests in dry bean. Students were also trained to identify root rots in the field.
- An irrigation facility has been installed in Misamfu to benefit the breeding program; with it, field research can continue in the off-season.

> *Seed grower associations help multiply and supply clean, reliable seed for more than 230,000 households growing beans in Zambia.*

Major Achievements

- Identified new sources of resistance to anthracnose, angular leaf spot, common bacterial blight, and rust in Uganda and Zambia.
- Identified several sources of drought tolerance. Sixty entries are being tested in Uganda and Zambia under normal and drought stress conditions.
- Confirmed that Ur-3, Ur-5, Ur-3+, CNC, and Ur-11 are genes from the Middle American cultivars that would confer resistance in Uganda. Excepting one rust isolate that caused a susceptible reaction on Ur-3, these genes can be used for breeding in Zambia.
- Identified genomic regions controlling BNF and anthracnose resistance

Research Capacity Strengthening

Collaborative research has enabled us to build research capacity in breeding activities and human resources. We have continued training and mentoring one PhD and two MSc students and trained three research assistants and five technicians in Uganda on modern technologies to capture field data and to reduce errors.

Two short-term trainings were organized for research assistants and technicians in Uganda to strengthen their research capability in data collection, including the use of new data collection tools associated with the breeding management system.

Achievement of Gender Equity Goals

We have ensured that women and men are equitably represented or involved in executing project activities and have achieved more than our goal of 30 percent female representation during project planning in Uganda.

> *Collaborative research has enabled us to build research capacity in breeding activities and human resources.*

In Zambia we have identified NGOs to partner with to ensure outreach and technology dissemination to female farmers, among them the Kusefya pa Ngw'ena Women's Farmer Group, the Shangila Seed Growers Association in Mpika, and the Participatory Village Development in Isolated Areas (PaViDIA) in Mporokoso and Luwingu. PaViDIA is working toward empowering women in communities in income-generating activities and seed and grain production for market sales to elevate income and reduce poverty.

Scholarly Accomplishments

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Patents

Plant Variety Protection Certificate 201500009 was issued for *Snowdon white kidney bean* on 2/26/2016.

Plant Variety Protection No. 201500008 was issued for *Eldorado pinto bean* on 7/6/2016.

Plant Variety Protection No 201500385 was issued for *Powderhorn great northern bean* on 6/3/2016.

Part of the research team in Zambia.

Angela Miranda, ICTA, stands alongside a field of climbing bean plants in Guatemala.

Development and Implementation of Robust Molecular Markers and Genetic Improvement of Common and Tepary Beans to Increase Grain Legume Production in Central America and Haiti
(SO1.A4)

LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

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Abstract of Research and Capacity Strengthening Achievements

Conventional plant breeding techniques and marker-assisted selection were used to develop dry bean cultivars with enhanced levels of disease resistance and greater tolerance to abiotic stresses.

The yellow bean germplasm line *PR1146-138* with BGYMV (Bean golden yellow mosaic virus), BCMV (Bean Common Mosaic Virus), and leafhopper resistance was released. The bruchid, BCMV, and BCMNV resistant red kidney germplasm *AO-1012-29-3-3A* was also formally released. Tepary bean populations are under development to increase seed size, improve agronomic traits, and combine disease resistance (BCMNV, rust, common blight). Tepary adaptation trials have been conducted in Honduras, Nicaragua, El Salvador, Tanzania, and Burkina Faso. Molecular markers of the *I* gene that confers resistance to BCMV and the Ur-3 and Ur-11 genes for resistance to rust have been developed and are being used for indirect selection for resistance.

GWAS enabled fine mapping of the recessive bc-12 gene and discovery of the genomic location for the bc-u gene for resistance to BCMV and BCMNV. GWAS was also used to identify new genes and QTL for halo blight resistance on chromosomes Pv04, Pv05, and Pv10. When data from the alpha-amylase inhibitor (AAI) amplification were analyzed, it was discovered that the products differed by 45bp, and the polymorphism was completely diagnostic between bean lines known to be susceptible and resistant to the common bean weevil.

Project Problem Statement and Justification

Increased bean production during the past 30 years in Central America and Haiti has been due to expansion of production in the lowlands (less than 1000 m). Greater heat tolerance combined with resistance to BGYMV increased bean grain 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 project focuses on developing bean cultivars with resistance/tolerance to both biotic and abiotic constraints in the tropical lowlands.

BCMNV threatens bean production in warmer bean production regions of Mexico, Central America, the Caribbean, and Africa. The recent arrival of BCMNV in the Caribbean made the

In Guatemala, a bean line susceptible to *Empoasca* (a species of leafhopper) showing leaf curling and edge burn (left), has been planted next to a line resistant to these *Empoasca* (right) to highlight the difference that can be achieved with improved varieties.

selection for resistance to this virus a priority breeding objective in Haiti, the Dominican Republic, and Puerto Rico. Collaborative research supported by LIL has resulted in the development and release of black bean cultivars and breeding lines that combine resistance to BCMNV and BGYMV. Small red bean breeding lines with the same combination of resistances are currently being developed at Zamorano. These 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.

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. This combination of resistances may also permit increased production of beans in Central America during the first growing season.

This project has used elite breeding lines with adaptation to the lowland tropics and different combinations of resistance to diseases (CBB, rust, ALS, web blight, and root rot) and tolerance to edaphic constraints as the base for the continued improvement of beans for its target countries.

The project plans to release red mottled, yellow, and white bean cultivars with enhanced levels of disease resistance in Haiti. Yellow, red mottled, and white bean breeding lines with BCMNV resistance will be available for LIL projects to test in Eastern Africa.

In the foreground, common bean plants grown from improved seed varieties resistant to BGYMV; in the background, beans susceptible to BGYMV.

Andean bean breeding lines developed at Sokoine University of Agriculture have a unique combination of traits that confer a high level of resistance to bruchids. These lines have been used as progenitors to introgress this resistance into black, small red, and white beans with resistance to BCMV, BCMNV, and BGYMV. Evaluations have been conducted in Central America and the Caribbean to measure the durability of the resistance when exposed to different genera and ecotypes of bruchids.

The project continues to screen germplasm to identify additional sources of resistance to diseases that limit bean production in Central America and the Caribbean. For example, more resistance to ashy stem blight is needed to improve adaptation to hot and dry environments, such as the dry corridor in Guatemala and southwestern Haiti. Ninety-three genotypes from the BASE 120 trial were screened against a *Macrophomina phaseolina* isolate from Juana Diaz, Puerto Rico (Mp-JD). Six of the 93 genotypes evaluated had low disease severity. Greater resistance to web blight is required to increase yield and seed quality of beans produced in more humid environments.

Tepary TAT Trial

There are regions and growing seasons in Central America, Haiti, and Africa that are too hot or dry to produce common beans. The tepary bean is a potential alternative grain legume for these stressful environments. In addition to heat and drought tolerance, tepary bean lines with resistance to CBB, root rots, BCMV, bruchids, and 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 bean. In addition to pyramiding these traits within tepary, interspecific crosses with common bean are being used to introgress these traits into tepary bean.

Marker-assisted selection helps bean breeders identify lines with desired combinations of traits, resulting in increased efficiency in developing improved breeding lines; however, molecular markers are only available for a limited number of traits; others are only effective in a specific gene pool. Developing new or more robust markers for bean breeding in the tropics is needed. This project will assist this effort through the development of the populations and information needed to identify improved markers for specific traits.

Objectives

1. Genetic improvement of common and tepary beans for Central America and Haiti.
2. Develop and implement robust molecular markers for traits of economic importance.

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 have focused on the most important biotic and abiotic constraints in lowland (less than 1,000 m) bean production regions in Central America and Haiti. Zamorano has coordinated the regional testing of small red and black bean breeding, while the University of Puerto Rico has coordinated the development and testing of Andean beans in the Caribbean—both in collaboration with CIAT. Multicountry testing expands the potential impact of the research. In addition to yield, field trials screen bean lines for resistance to ALS, powdery mildew, ashy stem blight, web blight, and efficiency for BNF and high temperatures.

In collaboration with Bioversity International and CATIE, more than 2000 trials were evaluated by farmers in the Trifinio region (borders of Guatemala, El Salvador, and Honduras), which is part of the Central American dry corridor. Another 1000 trials were conducted in Nicaragua.

Trial Name	Small red	Small black	Countries
Regional bean adaptation nursery (VIDAC)	42 entries + 2 checks	55 entries + 2 checks	7
Regional yield and adaptation trial	14 entries + 2 checks	14 entries + 2 checks	7
Regional Rojo de Seda Nursery (VIROS)	22 entries + 3 checks		3
Bean variety validation trial	9 entries + 1 check	9 entries + 1 check	4
Regional angular leaf spot trial (ERMAN)	10 entries + 2 checks		5
Regional web blight trial (ERMUS)	14 entries + 2 checks		5
Biofortified bean trial (AGROSALUD)	8 entries + 2 checks		6
Regional BNF trial (ERFBN)	8 entries + 2 checks		3
Regional high temperature trial (ERSAT)	20 entries + 4 checks		6
Regional drought trial (ERSEQ)	22 entries + 2 checks		6
Regional low fertility trial (ERBAF)	22 entries + 2 checks		5

Table 1. Trials distributed to Central American and Caribbean Bean Research Network collaborators during 2015–2016.

Greater tolerance to abiotic stress

Although disease resistance is the project's primary focus, the performance of bean breeding lines is evaluated in low fertility soils. Honduras and Puerto Rico were used to evaluate the performance of bean breeding lines for performance in a low N soil, root rot resistance, and high temperature. Results identified the black bean cultivar *XRAV-40-4* to have among the best root nodulation scores.

Bruchid resistance

Red kidney bean breeding lines were screened in Puerto Rico for bruchid and BCMV and BCMNV resistance. One of the bruchid and virus resistant lines, AO-1012-29-3-3A, was formally released, which has also been used as a progenitor to transfer BCMV and BCMNV resistance into breeding lines for Tanzania and to introgress resistance to bruchids into black, small red, red mottled, and light red kidney bean types. A seed increase of two black bean breeding lines that combine bruchid and virus resistance was conducted in Honduras to conduct on-farm trials to test the effectiveness of bruchid resistance with seed storage methods utilized by area farmers..

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

The Andean Diversity (ADP) panels have been screened in Central America and the Caribbean for specific traits; in Haiti, to powdery mildew, and in Honduras and Puerto Rico, for angular leaf spot. The Middle American Diversity Panel has been evaluated in low N environments in Central America and Puerto Rico 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 BGYMV, BCMV, and BCMNV. To expand the use of tepary bean in abiotic stress prone regions, this project has worked to incorporate newly identified resistances into tepary accessions in the ARS-TARS tepary breeding program and to initiate the introgression of virus resistance from common bean into tepary bean. Advanced breeding lines developed from these and previous breeding efforts 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 Tepary Diversity Panel (TDP) and breeding lines selected for disease and abiotic stress tolerance. In 2016, more than 10 accessions were identified in the TDP with resistance to the NL3 strain of BCMNV, and accessions are being tested against strains representing different pathogroups of BCMV and BCMNV to evaluate for broad resistance. Line resistance to BGYMV, ALS, and BNF previously identified in Honduras is being pyramided through a separate approach involving the generation of bulk breeding populations. These populations have undergone individual plant selection under biotic and abiotic stress in Honduras and Puerto Rico. In FY 2017, the project expects to have tepary breeding lines with disease resistance loci for further pyramiding in the future.

Superior lines have been included in the TAT and tested in the host countries for potential future release.

Objective 2. Develop and implement robust molecular markers for traits of economic importance

Develop and implement robust molecular markers for disease resistance genes

This project has leveraged results from the USDA Common Bean Agricultural Project and the USDA/DOE/JGI common bean sequencing project. The BeanCAP project developed a suite of approximately 3000 InDel markers distributed across all common bean chromosomes. These markers are codominant and designed to be functional in labs with a simple set of equipment and reagents (Thermal Cycler, gel chambers, and UV lamp). The power of these markers is that they are simple to implement and thus completely portable in all laboratories and are amenable to multiplexing with suites of markers.

Tepary breeding lines being tested under heat stress.

Multiplexing reduces the cost of genotyping an individual line. The release of the common bean whole genome assembled sequence allows for precise localization of each of these markers. The final key element that facilitates this project is the development, over the last fifteen years, of markers (mostly SCARS) that are linked, from 0-5 cM, to important target disease genes. While useful, there has been some difficulty in the portability of these markers from one laboratory to another. SCAR markers all have unique experimental conditions that preclude multiplexing, and greater than 5 percent recombination reduces effectiveness due to recombination between marker and target gene. In addition, these SCAR markers don't work across different market classes or genetic backgrounds. Contrastingly, most InDel markers developed at NDSU are market class specific, which will facilitate their use and increase their reliability.

Identify genetic materials for marker evaluation

Potential targets for improved marker development include:

- Bean Golden Yellow Mosaic Virus Resistance Genes and QTL (bgm, SW12, Bgp)
- Bruchid resistance genes (Arc2, Arl3, PHA and aAI3)
- BCMV and BCMNV (I, bc-3, bc-12)
- Bean Rust (Ur-3, Ur-4, Ur-5, Ur-11)
- Common Bacterial Blight (SAP-6, Xa11.4, Pv07-QTL)

For each of these targets, project scientists searched the published literature and communicated with breeders, geneticists, and pathologists 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 were identified using sequence information.
- InDel marker selection. After the marker location was determined, it was compared to the InDel database to discover InDel markers that straddle the marker's physical location. Those InDel markers were then used in PCR amplification to determine the definitive marker unambiguous in its predictive power.

Development of molecular markers for BCMV, halo blight, and BGYMV resistance

New SNP-based markers for MAS of the *I* gene that confers resistance to BCMV have been developed and are being used for indirect selection for this resistance in the project's breeding program. Additionally, a candidate gene for *I* has been identified. Primers spanning the genomic region containing this gene are being used to sequence the gene in resistance and susceptible lines to develop gene-based markers and to provide the molecular tools for eventual cloning of the gene.

For GWAS, more than 1,000 lines representing three diversity panels—Andean, Durango, and Snap bean—were phenotyped for reaction to the NL-3 strain to detect the presence of the *I* gene and were genotyped with available SNP data sets possessing approximately 25,000 (Porch lab), two million (McClean lab), and 30,000 (Porch/Hart lab) SNPs, respectively. The Durango and Snap bean diversity panels were also screened with NL-8 strain. The GWAS for 200 Durango lines with reaction to both NL-3 and NL-8 strains of BCMNV with 2 million SNPs enabled fine mapping of the recessive $bc\text{-}1^2$ gene and discovery of the genomic location for the *bc-u* gene. The GWAS peak for $bc\text{-}1^2$ is located between two candidate genes that are being sequenced for more in-depth analysis.

A global collaboration was sparked by Andy Tock, a PhD candidate from University of Warwick, Wellesbourne, UK, when his results on mapping halo bacterial blight resistance to Race 6 was found to complement our unpublished results. Together these collaborative results encompassing linkage mapping in four RIL populations and GWAS of 400 ADP lines in the field have revealed new genes and QTL for halo blight resistance on chromosomes Pv04, Pv05, and Pv10.

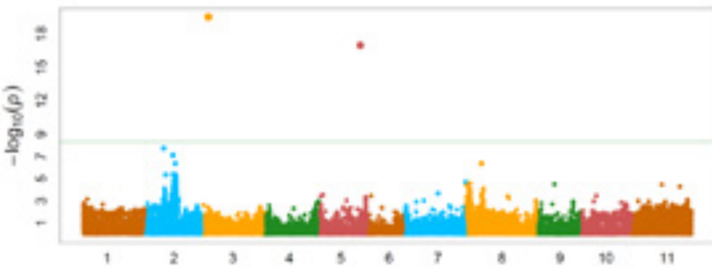

Figure 1. Manhattan plot detecting *bc-1*^{2} and *bc-u* genes.

The presence of the 5398 SNP chip enables rapid development of linkage maps with dense marker coverage for QTL discovery. We are revisiting an old RIL population Dorado/XAN 176 from the UPR-breeding program (1992) that was sparsely populated with RAPD markers but nonetheless was used to discover and generate markers for the SAP6 QTL for common bacterial blight resistance and the SW12 QTL for resistance to BGYMV resistance.

The Dorado/XAN 176 RIL population has been submitted for SNP genotyping to develop a denser linkage map to contribute to ongoing efforts by SO1.A4 and CIAT researchers to develop more tightly-linked breeder-friendly markers for these two QTL. A better marker for SW12 QTL is considered a critical need for breeding for high levels of resistance to BGYMV because of recent severe outbreaks of the disease in Central America. Populations are under development at Zamorano that segregate for the dominant gene *Bgp-1* that confers resistance to pod deformation in the presence of BGYMV. Individual F_5 plants were selected at Zamorano for normal and deformed pods. $F_{5:6}$ plant rows will be screened for BGYMV resistance during the upcoming growing season. The data will be used by Dr. Phil McClean at NDSU to identify a molecular marker for this important gene for resistance to BGYMV.

Development of molecular markers for rust resistance

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

Dr. Pastor Corrales screened 301 members of the Middle American Diversity Panel (MDP) to assess their response against bean rust races that can discover *Ur-3* and *Ur-11* specificity. Previously, Dr. McClean's group had placed the Ur-3 resistance gene in the vicinity of 47 Mb on Pv11. In addition, a group of five indel markers were noted to co-segregate with Ur-3 resistance in 24 genotypes. This year the MDP was scored for those markers. That data is found in table 2.

Indel marker position (bp) on Pv11	# MDP mismatches	# F_2 recombinants
46,961,210	18 (6%)	0
46,981,156	10 (3%)	0
46,985,504	10 (3%)	unknown
47,016,881	13 (4%)	2
47,768,400	31 (10%)	9

Table 2. Genetic analysis of the MDP and UI 114 x C-20 F_2 population with indel markers associated with the *Ur-3* resistance locus of common bean. The MDP data represents the number of mismatches out of 301 lines with percentage mismatches in parentheses. The F_2 data represents the number of recombinants in a population of 811 individuals.

The data clearly place *Ur-3* at the proximal end of these markers. Additional work is under way to further map additional indel markers that are proximal of the marker at 46,961,210. The goal is to discover a marker that shows recombinants in the F2 population. This result will place *Ur-3* is a definitive interval from which a candidate gene can be discovered.

Similar efforts are under way, but not as advanced, for *Ur-6* and *Ur-11*. For *Ur-6*, a F_2 population of approximately 2000 individuals is ready for screening with race 47 (uncovers the *Ur-6* resistance specificity). For *Ur-11*, 30 F1 plants are being grown and F2 seeds will be harvested. That F2 population will be challenged with the appropriate bean rust race to score for the *Ur-11* resistance specificity. That data will be coupled with a molecular screening for the five indel markers discovered this year to be closely associated with *Ur-11*. These markers were discovered by scoring the MDP and looking for markers with only a few mismatches. That data presented in table 3 shows two perfect markers that can be immediately implemented for the screening for the *Ur-11* resistance locus in common bean.

Indel marker position (bp) on Pv11	# MDP mismatches	# F_2 recombinants
47,956,000	4 (1%)	0
48,242,933	0 (0%)	0
48,356,332	2 (0.6%)	unknown
48,414,723	0 (0%)	2
48,459,800	3 (1%)	9

Table 3. Genetic analysis of the MDP and UI 114 x C-20 F_2 population with indel markers associated with the *Ur-3* resistance locus of common bean. The MDP data represents the number of mismatches out of 301 lines with percentage mismatches in parentheses. The F_2 data represents the number of recombinants in a population of 811 individuals.

The better, more tightly linked markers for the *Ur-3* and *Ur-11* rust resistance genes developed to date by SO1.A4 and ARS (Beltsville) are being used for MAS and characterization of advanced breeding lines. These markers are easier to assay and more diagnostic than the previous RAPD-based markers, and are expected to have worldwide utility for detection of the genes across market classes and breeding programs.

Develop Molecular Markers for Bruchid Resistance

A collaborative breeding effort led to the development of breeding lines in which the arcelin (ARC or ARL)-phytohemagluttin (PHA)-alpha-amylase inhibitor (AAI) locus (collectively known as the APA locus) from tepary accession G40199 was introduced. This locus is presumed to be the source of bruchid resistance and results in significantly reduced seed storage damage by the common and Mexican bean weevil

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

Given that the arcelin, and not the alpha-amylase locus, is thought to be the causative protein associated with resistance, a sequence analysis of multiple clones of arcelin-specific amplification products was performed. This study focused on the four resistant lines, the tepary source, and other tepary lines. To date all of the sequence data have been collected and are being analyzed.

Human Resource and Institutional Capacity Development

Formal and informal training activities were conducted to enhance the capacity of host country bean research programs to develop and release bean cultivars that increase production or reduce losses in target countries.

Informal training

In-service training was provided at NDSU for LIL scientists and graduate students to review recent advances in sequencing the bean genome and the utilization of SNP arrays to develop InDel markers for traits of economic importance.

A workshop was held in Puerto Rico to teach personnel from Central America and the Caribbean about bean research related to abiotic stress, specifically breeding for tolerance to low soil fertility and resistance to drought and high temperatures.

Sankara seed increase - Zanmi Agrikol

Major Achievements

- The BGYMV-, BCMV-, and BCMNV-resistant and early maturing black bean line *MEN2201-64ML* was released in Honduras as *Lenca Precoz*. Having also performed well in drought-prone regions of Haiti, MEN2201-64ML seed will soon be distributed to farmers in Central America and Haiti.
- XRAV-40-4, a multiple disease-resistant black bean adapted to the humid tropics, was released in Central America as *Azabache 40* and in Haiti as *Sankara*.
- The small red line MIB 397-72 was released in Honduras as the biofortified bean cultivar *Honduras Nutritivo*. Selection for resistance to BGYMV, MIB 397-72 contains 25 percent more iron than traditional small red cultivars.
- The small red line RS 901-6 was released in collaboration with INTA in Nicaragua as the cultivar *INTA Jinotega*, selected for resistance to BGYMV, earliness, and its *Rojo de Seda* commercial grain type.
- The Tepary Diversity Panel (TDP) composed of 314 accessions was developed and genotyped with SNP markers using Genotyping by Sequencing (GBS). This panel has been evaluated for a number of different traits including agronomic

traits in the field under abiotic stress, and CBB, BNF, and response to NL3 inoculation. QTL on chromosomes 1 and 11 of tepary bean (using common bean as the reference genome) were found for resistance to BCMNV.

- Rust resistant white bean breeding lines DPC-40 and XRAV-40-4 were used as parents to introgress high levels of rust resistance into black beans to ensure multiple virus resistance.
- Yellow bean lines that combine the bgm-1 gene for resistance to BGYMV and the *I* gene for resistance to BCMV were developed and tested in Puerto Rico, Angola, and Haiti. *PR1146-138* also expressed tolerance to leafhoppers and produced a yield of 1,884 kg/ha over seven environments.

Tepary breeding lines being tested under heat stress.

- The virulence patterns of *Pseudocercospora griseola* isolates, the causal agent of angular leaf spot in common bean, from Honduras and Puerto Rico were studied. Important sources of resistance for the two isolates from Puerto Rico were identified.
- The small red bean breeding line IBC-301-204, selected at Zamorano for resistance to BGYMV, BCMV, and tolerance to low fertility, was released in Nicaragua as *INTA Centro Sur*.
- The small red bean breeding line RS 901-6, a preferred Rojo de Seda commercial grain type selected at Zamorano for earliness, resistance to BGYMV, BCMV, and tolerance to drought was recently released in Nicaragua as *Rojo Jinotega*.

Research Capacity Strengthening

LIL plant breeders assist bean research programs in Guatemala and Haiti to develop the capacity to develop populations and test breeding lines that will lead to the release of improved bean cultivars. This should contribute to the long-term sustainability of bean breeding activities in the region. The ICTA bean research team has developed numerous populations having different breeding objectives and is evaluating bean breeding lines in the field and using marker-assisted selection to identify lines that possess the *Co-4*^{2} allele for resistance to anthracnose. Dr. Porch provided bulk populations of black beans to Haiti to provide National Seed Service researchers with experience making field selections and managing breeding lines.

This Legume Innovation Lab project continues to collaborate with many CRSP alumni institutions. This collaboration extends the potential impact of Legume Innovation Lab research and generates information that is valuable to the global bean research community.

Scholarly Accomplishments

Beaver, J. S., Prophete, E., Démosthène, G., & Porch, T. G. (2016). Registration of PR1146-138 Yellow Bean Germplasm Line. *J. Plant Registrations*. 10:145-148.

Estevez de Jensen, C., Porch, T. G., Colley, J., Gonzalez, O., Porch, T. J., & Beaver, J. S. (2016). Virulence of *Macrophomina phaseolina isolates* in common bean (*Phaseolus vulgaris*) genotypes. Poster presented at the 2016 Pan-African Grain Legume and World Cowpea Conference in Livingstone, Zambia, from February 28 to March.

Porch, T. G. (2016). Técnicas para desarrollar frijol con mayor resistencia al cambio climático. Paper presented at the 2016 Annual Meeting of the PCCMCA in San José, Costa Rica, from 5 to 7 May.

Porch, T. G., Cichy, K., Wang, W., Brick, D. M., Beaver, J. S., Santana-Morant, D., & Grusak, M. (2016). Nutritional composition and cooking characteristics of tepary bean (*Phaseolus acutifolius* Gray) in comparison with common bean (*Phaseolus vulgaris* L.). *Genetic Resources and Crop Evolution*. doi:10.1007/s10722-016-0413-0.

Rosas, J. C., Beaver, J. S., Porch, T. G., Beebe, S.E., Burridge J. D., & Lynch, J. P. (2016). Evaluation of common bean lines for adaptation to high temperatures in Honduras. Poster presented at the 2016 Pan-African Grain Legume and World Cowpea Conference in Livingstone, Zambia, February 28 to March 4.

Torres, S. Valentín, Vargas, M. M., Godoy-Lutz, G., Porch, T. G. & Beaver, J. S. (2016). Isolates of Rhizoctonia solani can produce both web blight and root rot symptoms in common bean (*Phaseolus vulgaris* L.). *Plant Disease* 100:1351-1357.

Professional Recognition

James Beaver received a certificate of recognition from the House of Representatives of the Commonwealth of Puerto Rico for contributions to local agriculture.

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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Abstract of Research Achievements and Impacts

Multilocation screening of a cowpea aphid resistance panel was completed using uniform test protocols to characterize resistance to aphids and to identify cowpea aphid biotypes in three African and one U.S. locations. Differences between U.S. and African aphid populations were found based on molecular sequence, and three independent resistance QTL were discovered. Cowpea populations segregating for resistance to pod bugs, flower thrips, and aphids were advanced, phenotyped, and genotyped for QTL discovery for use in marker-assisted breeding across project countries. Breeder and Foundation Seed were multiplied and distributed to farmers' organizations for Certified Seed production of five recently released large white-seeded varieties in Senegal and four prerelease LIL advanced lines in Burkina Faso. In California, advanced lygus, aphid, and disease-resistant blackeye lines were on-farm and on-station performance tested.

Thirteen African students, including four women, are engaged in degree training programs (seven PhD, six MS/MPhil). A capacity strengthening award to INERA supported the development of modern cowpea seed storage capability in Burkina Faso. Continuous short-term training occurred with each host country through iterative data analysis and interpretation cycles, a workshop in Zambia, and training visits to UCR.

Project Problem Statement and Justification

Low productivity of agriculture is central to rural and urban poverty in Africa. On-farm cowpea yields in West Africa average 240 kg/ha, although potential yields are often five to 10 times greater. Most of the loss is due to drought, poor soil fertility, and insect pests.

By targeting insect tolerance and combining it 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 that are resistant to pests would increase marketing opportunities for cowpea farmers and traders in both West Africa and the United States.

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

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 have tested the genetic relatedness of five sources of cowpea aphid resistance. Field observations in Africa and California indicate differential effects of resistance sources on aphid populations from different cowpea production areas. Uniform screens in field locations across all project NARS (Burkina, Ghana, Senegal) and California were conducted in field plots or in screenhouses, with four-fold replication on cowpea lines seed-multiplied and shared in 2014-15. This multisite phenotype screening for resistance response was repeated in FY16 to provide two years of data at each location.

The 2016 screenhouse test in Senegal revealed the following reactions: resistant (KN1, 58-57, Kvx 295-2-124-99, CB27, INIA 19); moderately resistant (Sarc-1-57-2); susceptible (Apagbaala, Bambey 21, IT82E-18). (See table 1.)

The lines IT97K-556-6, Tvu 1158, and Vita seven did not germinate. 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, confirmed in 2016. In Burkina Faso, the seedling-stage screening of the aphid resistance panel in pots at the INERA Saria Station gave results that confirmed those obtained from the previous year's screening with aphid from Kamboinse and Saria. In California, lines Kvx 295-2-124-99, INIA 19, Sarc-1-57-2, IT97K-556-6, and Tvu 1158 were resistant. Analysis of the multilocation screening results continues.

Genotypes	Nr plants: 6/3	Nr dead pl.: 6/15	Nr dead pl.: 6/22	Nr plants: 6/22
KN - 1	6	1	1	4
58 - 77	2	0	0	2
KVx 295 - 2-124-99	6	0	1	5
Bambey 21	5	2	3	0
Apagbaala	6	3	3	0
IT 82E - 18	5	2	1	2
CB27	4	0	0	4
INIA 19	3	1	0	2
IT97K - 556 - 6	0	–		
Sarc 1 - 57 -2	5	1	2	2
TVU - 1158	0	–	–	–

Table 1. Aphid resistance panel screening results, Senegal, 2016: Planting: 24 May 2016. Date of infestation : 03 June 2016. First observation: 15 June 2016. Second observation: 22 June 2016.

In testing the mode of inheritance and the genetic relatedness of these lines, F1 populations were developed between each of these lines with *Apagbaala*, an aphid susceptible popular variety in Ghana, and the resistant lines were also crossed with each other. These populations were advanced to the F2 at SARI. The segregation ratio in the F2 population fit a 3:1 ratio for a single dominant between IT97K556-6 and Apagbala (resistant and susceptible) gene ($\chi 2 = 3.26$, $P = 0.0707$). The F2 were advanced to F3 and F3 families were screened; a (1R:2H:1S) segregation ratio confirming the presence of a major gene controlling resistance. Segregation in the SARC-1-57-2 x IT97K556-6 F2 indicated two independent for aphid resistances operated in in the F2 population. Other findings confirmed that the SARC-157-2 aphid resistance is distinct from that in the IT97K556-6 line, which is controlled by a major gene on LG7 and a minor gene on LG1. From this work, breeders can pyramid different resistant genes into elite cowpea varieties. The best performing lines will be multiplied in greenhouse culture this winter for expanded field performance testing in FY17.

A screenhouse that functions as a greenhouse solar dryer to facilitate the drying of cowpea during the rainy season in Ghana.

We are working with Drs. B. Pittendrigh and M. Tamo on the characterization (molecular fingerprinting) of 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 Kamboinse, Pobe-Mengao, and Farako-Ba—representing three diverse cowpea production zones. Five samples were also collected in different fields in the Bambey, Senegal area. Aphid samples from SARI, Tamale, Ghana, and UCR, Parlier, Fresno Co., California, were used to compare old-world and new world *Aphis craccivora* by complete sequencing of their mitochondrial genomes (mitogenomes). The comparison showed only very minor differences between the sequences (99.7 percent identity), reflecting only very recent divergence of the old and new world forms.

1.2 Flower thrips resistance

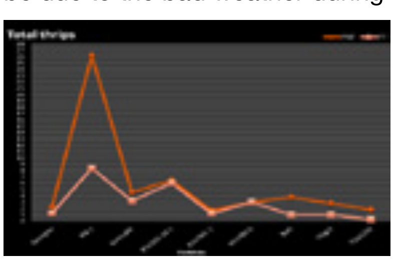
In recent work on QTL discovery, we identified an SNP-mapped loci (*Cft-1* and *Cft-2*) for flower thrips tolerance in the cross Sanzi x Vita 7; these loci are promising for introduction and selection in breeding progenies but require better definition through phenotyping.

Above and below, researchers and farmers spread harvested cowpea inside the greenhouse to dry them during the rainy season.

Additional sources of thrips tolerance are 58-77 (biparental RIL population from 58-77 x Yacine is available) and Tvx3236. In Senegal, during the 2016 rainy season, the RIL populations Sanzi x Vita 7, and 58-77 x Yacine were each planted in two trials with flower Thrips control and no spray comparison plots. Data were obtained on the number of peduncles and pods and number of thrips in five flowers for the first population. Thrips damage rating was also obtained for both populations. The families derived from crosses of resistant (Sanzi x 58-77) and large seeded varieties (ISRA-3178 and ISRA-3217) and were advanced to the F4 during the off-season and rainy season. The M4 generation of selected Yacine lines was also evaluated and additional selections made. Promising results were obtained for the second time after eight months of Yacine and Melakh M4 lines tests for reaction to bruchids.

At SARI, Ghana, Dr. Kusi received seed in FY15 of the Sanzi x Vita7 and Yacine x 58-77 RIL populations from Senegal for phenotyping for flower thrips tolerance. Given the limited seeds per line received, the populations were planted to increase seeds. The two RIL populations were planted in two locations during this FY 16 main cropping season in Manga in the Sudan Savanna and Tamale in the Guinea Savanna. Initial data on Thrips samples showed high insect counts against some of the lines in Tamale, while the counts in Manga were low. Data are currently being compiled and the results will be used for QTL mapping. 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 inbred populations segregating for seed color (including white) and flower thrips resistance were evaluated for QTL discovery and breeding. One parent is *Songotra*, a high yielding black-eye resistant to Striga but thrips sensitive. The second parent carries aphid resistance. The seeds produced from each of the single-seed descent plants were phenotyped for both flower thrips and Striga resistance. A total of 251 recombinant inbred lines were evaluated for Striga and flower thrips. Different reactions of cowpea RILs to Striga were found in the field and in pot experiments; 27 RILS were found resistant similar to the resistance donor, while 224 RILs were susceptible. A low number of flower thrips occurred after the flower sampling due to the weather conditions. The level of thrips infestation was very low at the Manga station, but could be due to the bad weather during the dry season.



Plot of flower thrips numbers indicating resistance and susceptibility levels.

In Burkina Faso, nine cowpea genotypes were screened for flower thrips tolerance. From this screening, genotypes IKVx780-1 and KVx780-6 (both close to release), plus KVx165-14-1 and TVx3236 have shown good tolerance levels to flower thrips. Nafi has shown a higher level of tolerance compared to the other released varieties.

Crosses are being made between tolerant genotypes and released susceptible varieties and will be genotyped and phenotyped for genetic analysis and marker discovery.

1.3 Pod-sucking bug resistance

The *Heteropteran Coreid* pod-sucking bugs are a major yield suppressor in Burkina Faso, Ghana, and neighboring countries. To identify genes or QTL for resistance to pod-sucking bugs we used biparental resistant x susceptible segregating populations in Burkina Faso in FY 14 and FY 15 to map QTL and initiate their selection as a new breeding target. The primary resistance donor is IT86D-716. Two existing F2 populations generated from resistance donor IT86D-716 with parents Kvx771-10G (Nafi), Tiligre, Gourgou, and IT98K-205-8 enable combining Striga resistance with pod-sucking bug tolerance. The parents were genotyped through LGC Genomics and the F2 and F3 populations are being phenotyped for pod bug resistance in Burkina Faso. A second set of segregating materials was developed from crosses between six parents involving the resistant IT86D-716 to provide more viable populations. Leaf material from the new sets at F7 has been collected and was SNP genotyped during late 2016, for QTL mapping resistance to pod bugs, striga, aphids, and bruchids contained in the same population set.

For the three insect groups (aphids, thrips, pod bugs), we collaborated with Drs. Pittendrigh and Tamo (SO1.B1) to utilize our project trial sites to collect insect samples for use in molecular characterization of the insect populations. Collections were made at all test locations, allowing a robust comparative profiling of insect populations. We have tested a protocol for insect DNA collection in which insects are placed in plastic bags with silica gel packs, which dries the insect samples and preserves the DNA. Tests on aphid DNA with primers for the COX1 gene demonstrated excellent DNA integrity. As described in Objective 1.1, aphid samples from SARI, Tamale, Ghana and UCR, Parlier, Fresno Co. California were used to compare old-world and new world *Aphis craccivora* by complete sequencing of their mitochondrial genomes (mitogenomes). In Burkina Faso, pod bugs were collected from Kamboinse, Pobe-Mengao, and Farako-Ba. In Senegal samples were obtained for cowpea aphids in the Bambey production area.

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

Phenotyping of cowpea GWAS lines in Ghana: Field performance evaluation for yield.

2.1. Genotyping capability was used to advance the BT gene introgression for *Maruca* resistance with our SNP marker panel. The goal is to expedite the selection of lines with the highest percentage of elite recurrent parent content in each country (e.g., improvement of elite variety IT97K-499-35 in Ghana and several elite local varieties in Burkina Faso, including Moussa Local, Gourgou 3, 7, and 11; IT98K-205-8; and KVX 745-11P). The phenotyping of the breeding lines for *Maruca* was done in the host countries with funding from USAID through the African Agricultural Technology Foundation (AATF). The genotyping mostly followed the same general protocol as outlined-under Objective 1 work. Leaf samples from young screenhouse 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 (KASP). The genotype data were analyzed for molecular scores using Backcross Selector software.

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

In Senegal, a new version of Melakh resistant to Striga was obtained through marker-assisted selection. The selected BC4 F3 families were multiplied during the rainy season. Additional multiplication will be done during the 2017 off-season for on-farm demonstration. The line ISRA-3006 was also multiplied. This line was yield-tested earlier and had good performance with larger grain size and same color. It is also earlier maturing than the local variety.

Phenotyping of cowpea GWAS lines in Ghana: Field performance evaluation for yield, screening for drought tolerance using terminal drought stage screening on a wet plot.

The cowpea MAGIC population was multiplied during the off-season and introduced in a preliminary yield trial at the ISRA/CNRA Bambey station during the 2016 rainy season. Data were obtained on time to flowering, maturity, numbers of peduncles and pods, 100-grain weight, and yield. The five varieties released in 2015 (Lisard, Thieye, Leona, Kelle, and Sam) were again multiplied on 0.5 ha each in 2016 for additional Foundation Seed production at the Bambey station. The new version of Striga resistant Melakh and ISRA-3006 were multiplied for Breeder Seed on about 0.01 ha.

Phenotyping of cowpea GWAS lines in Ghana: Field performance evaluation for yield, screening for drought tolerance using both seed-box and field protocols for seedling-stage and terminal drought stage tolerance, repectively.

In Burkina Faso, 20 prerelease CRSP advanced lines developed by the breeding team were on-farm performance tested in 2013. The four best performing of the lines tested in the interim years plus two standard checks were re-evaluated in the off-season in FY 16, emphasizing yield and grain quality plus any disease susceptibility. About 20 kg of Breeder Seed of each of these lines will be available at the INERA Saria Station, and will be used to initiate Foundation Seed production in the FY17 off-season if lines are approved for release.

In California, advanced breeding lines for blackeyes were field tested for release potential, based on performance data collected in previous on-station trials. These CRSP-developed lines carry a combination of lygus bug tolerance, and root-knot nematode and *Fusarium* wilt resistance. The 11 lines plus the standard variety CB46 were tested under insect-protected conditions, while a no-insecticide unprotected versus insecticide protected split-plot lygus screening trial was conducted with three lines with lygus bug tolerance.

Trials comparing yield and grain quality of five new blackeye breeding lines together with CB46Rk^2, CB46, and CB50 were conducted under early-planted, double-flush production conditions at the Kearney Station. The two most promising lines were evaluated with CB46Rk^2 and CB46 in large strip plots at Tulare Co. Some advanced lines had higher grain yield than CB46 at Kearney, and two lines had equivalent yield to CB46 at the Tulare Co. farmer field location. Some lines also combine the advantage of stronger, broad-based resistance to root-knot nematodes and resistance to *Fusarium* wilt Race 4, with seed size consistently equal to or larger than CB46 but smaller than CB50. CB46Rk^2, a new version of CB46 with improved resistance to root-knot nematodes, performed best in 2015 at Kearney. In 2015 three lines first selected in 2007–2009 were evaluated under insect-unprotected conditions at Kearney. From the 2015 trials, we chose the most promising lines (combination of yield, seed quality, and resistance) for performance testing in the 2016 main season.

Four trials were planted in May 2016 in Tulare Co. with four lines (CB46, N2, 10K-29, CB46Rk^2) in large 0.5 acre field-length six-row strips in four different farmer fields. Trials at the UC Kearney station were planted in June 2016 with seven lines (CB46, CB46Rk^2, two 10K lines, and three N lines) in four-extended row four-fold replicated RCBD. Harvesting, threshing, and seed cleaning was under way at 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 2016 main rainy season in Burkina Faso, new varieties were multiplied as Breeder Seed for additional Foundation Seed production.

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

Short-Term Training

Short-term training in modern breeding techniques of a young scientist from SARI and a member of the LIL research team was conducted at UCR from March to September 2016. Training included greenhouse, laboratory, on-station, on-farm experimentation, and molecular data processing.

Training in molecular breeding for young trainee breeders and NARS scientists was continued at a two-day training workshop in February 2016 in Livingstone, Zambia.

Degree Training

Degree training was conducted for two graduate students in the report period at UCR and eleven in Africa—three in Senegal, six in Ghana, and two in Burkina Faso.

Major Achievements

A differential cowpea panel of aphid resistance sources and control lines was seed-multiplied and used in multilocation field screening and screenhouse seedling screening during FY15 and FY16. Using a uniform test protocol for aphid biotype and resistance screening under field and greenhouse conditions, several aphid resistance sources effective against both U.S. and West African aphid populations were identified. This has allowed differentiating biotypes, for example between Senegal and California CB27 has a resistant reaction in Senegal while susceptible in California. Reaction in Senegal and Ghana seems to highlight similar biotypes in the two zones.

A Senegal farmer stands in a field of an improved cowpea variety.

An improved version of Melakh with Striga resistance was developed by ISRA, Senegal, and multiplied for Breeder Seed. The line ISRA-3006 with speckled black grain (Mougne type) was also multiplied for Breeder Seed and will be introduced in demonstration on-farm locations next season.

A new segregating population between IT86D-716 and Nafi was developed in Burkina Faso for use in QTL mapping for pod bug resistance, and is under phenotyping and genotyping analysis.

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

Four prerelease CRSP advanced cowpea lines were re-evaluated in multilocation tests at Saria, Pobe, and Kamboinse during the 2015 main rainy season and re-tested in the off-season in FY 16 (October, 2015– April, 2016), emphasizing yield and grain quality, plus any disease susceptibility.

Achievement of Gender Equity Goals

During the year under review 200 farmers, about 70 percent women, were exposed to new improved cowpea varieties resistant to Striga and aphids by SARI, Ghana. They were trained in best agricultural practices suitable for cowpea production using IPM principles to reduce indiscriminate application of chemical insecticides.

In Senegal, with the farmers' organization RESOPP and the IITA/USAID Cowpea Out-Scaling Project in West Africa (COSP), training of its members on seed production and postharvest operations was continued. More than 200 women producers were trained in FY15-16. In Burkina Faso, 215 women producers were trained on cowpea production and seed storage and about 50 women conducted demonstration tests in FY 16. In the Certified Seed production group of 58 farmers, 39 were women and 19 men. Plans were made for a training program for women on cowpea processing and finance management in November 2016.

Scholarly Accomplishments

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A farmer in southern Benin releases pod borer parasitoids as part of the IPM project.

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

(SO1.B1)

LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

Dr. Barry Pittendrigh, University of Illinois at Urbana–Champaign, October 1, 2015–July 15, 2016, and Michigan State University, July 16, 2016–present

COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

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Mr. Laouali Amadou, INRAN, Niger

Dr. Ibrahim Baoua, University of Maradi (collaborator with INRAN)

Dr. Stephen Asante, SARI, Ghana

Dr. Moses Mochaih, CRI, Ghana

Dr. Julia Bello-Bravo, UIUC

Mr. Eustache Biaou, INRAB-Benin

Abstract of Research and Capacity Strengthening Achievements

Understanding and solutions for the major pests of cowpeas in Benin, Niger, Burkina Faso, and Ghana have continued to progress. Specifically, pest populations have been characterized through molecular tools, with a focus on mitochondrial polymorphisms. Solutions to these pest problems have been developed and advanced, including cross-country releases of biocontrol agents and a larger scale testing of neem and *Maruca*-specific viral combined sprays.

Analysis on the use of educational tools involving animations and voice overlays in videos has continued, using local languages as a scalable system to deploy research outcomes on creating and deploying locally sourced pest control solutions. Capacity building efforts include undergraduate and graduate training in host country programs, training of technicians across countries, and testing the animated educational approach, including ICT training sessions and feedback on the Android App that allows collaborating organizations to easily access and use these materials in their educational programs.

Collaborations 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 have continued.

Project Problem Statement and Justification

Insect pests of cowpeas dramatically reduce yields for cowpea farmers in West Africa, many of whom live on less than a few US dollars per day. The greatest biotic constraints on cowpea production in northern Nigeria, Niger, Ghana, and Burkina Faso are insect pests in the field, particularly the legume pod borer, two types of coreid pod-bugs, a groundnut aphid, and three different thrips. The project has followed a three-step approach of defining the pest problems, developing appropriate pest control solutions, and developing strategies for scaling these solutions.

Bruchids are among the insect pests causing devastation to cowpea in West Africa.

Project scientists have continued to develop an in-depth understanding of the pest populations through a combination of field experiments and molecular tools that characterize and compare pest populations.

The project team has developed solutions that develop local cottage industries that produce biopesticides for local sale and use, facilitating the potential for local value chains that make and sell ecologically friendly pest control solutions. These efforts are already realized with local neem production businesses in Benin.

Project scientists have continued to investigate biological control agents in the biocontrol pipeline, with promising candidates released in the field, using approaches developed to scale their releases cost-effectively. Additionally, project scientists

1. have developed scalable educational solutions for all literacy levels to train people on the pest control strategies in their own languages
2. have gathered experimental data indicating people learn equally well or better from animations than from traditional extension presentations
3. are exploring pathways for passing educational animations off to other groups that can deploy them in their own educational programs.
4. have continued undergraduate and graduate training to ensure grain legume scientists to continue research in the future
5. have been working with NGOs and local communities for pass off of outcomes,
6. developed 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.

Objectives

The project's objectives emerge from a vision, supported and intertwined with capacity building, called *IPM-omics*—a system to develop and to deploy scalable pest control solutions. IPM-omics is best defined as an equation: IPM-omics = the project objectives, which are as follows.

1. Define the pest problems.
2. Define and develop appropriate solutions.
3. Scale the solutions for greater impact.
4. Institutional capacity strengthening.

Technical Research Progress

To assess the impact potential of the projects' IPM strategies in West Africa, datasets have been researched, developed, implemented, and analyzed during FY 2016. Project scientists have continued to research and to develop scalable solutions, with the potential and actualization of larger-scale impact through donor community buy-in.

Objective 1. Define the pest problems.

1. Scouting, field experiments, and light traps
2. Genomic markers to define pest and biocontrol agent populations: movement patterns and sources of the outbreaks
3. Computational modeling
4. Understanding the biology of pest populations to drive pest control strategies.

1.1 Scouting and field experiments

The IITA, INERA, INRAN, CRI, and SARI teams all continue to work on analyzing pest populations during and outside the cowpea cropping cycles. Insects, such as *Maruca vitrata*, found on alternative host plants are sent to UIUC for molecular analyses. Additionally, the INERA team has continued experiments on pest populations in the dry season where an additional cowpea cycle could be planted when irrigation is possible.

Bruchids destroying cowpea grain

1.2 Molecular Analyses of Pest Populations

UIUC and MSU have continued to receive pest populations from IITA for molecular analysis from numerous host plant populations across Benin, Niger, Burkina Faso, and Ghana. Similar sample collections of insects have been received from our teams in Burkina Faso, Niger, and Ghana. This past year's focus has been predominantly on SNP analysis of mitochondrial genes. One additional series of experiments includes populations of aphids collected by the UC-Riverside team (SO1.A5) on different lines of cowpeas. We have been comparing these aphid populations to determine if they are distinct biotypes.

1.3 Computational Modeling, GIS systems, and Online Systems

The UIUC/MSU and IITA teams continue to work on a flowchart system that will be used in predictive responses to cowpea farmers on when and where they can intervene in pest control strategies. These teams are also continuing to explore the use of GIS systems to couple our other datasets with GIS data. The UIUC team is continuing to summarize all published material for a website that will be online by the end of the project.

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

IITA has continued olfactometric studies involving the egg parasitoid *Gryon fulviventre* as attracted by putative male aggregation pheromones of the coreid bug *Clavigralla tomentosicollis*. The headspace volatile of both male and female *Clavigralla* spp. were collected without food and analysed, which allowed determining chemical profile (different components) for the three species. For each sex, headspace volatiles were collected more than five times and analysed separately. After comparison of both males and females of each species, specific male components were identified and are being characterized.

Objective 2. Develop appropriate solutions.

We have developed a biocontrol and biopesticide pipeline to develop a series of environmentally and economically appropriate pest control solutions.

2.1 Novel* Maruca *parasitoids available for screening

Investigation of the maternal factors responsible for the parasitization success in *T. javanus*, one of the best biocontrol candidates against the pod borer *Maruca vitrata*, has continued. After a series of observations targeting the *T. javanus* female genital tract (particularly the venom gland), the study focused on phenotyping the parasitized larvae and investigating the live stages of the parasitoid larva inside the body of the pod borer larva. This study yielded spectacular pictures of the different live stages.

Further studies confirmed the parasitoid's ability to discriminate already parasitized larvae; there is a high probability that the Doufour's gland might be involved in secreting marking volatiles.

Life stages of the parasitoid *Therophilus javanus*, dissected from developing pod borer *Maruca vitrata* caterpillars, days 2 to 11 after parasitization

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

After project scientists' initial success using three PCR primers available for the detection of *Beauveria bassiana,* of which $SCB9_{677}$ was revealed to be the best for our *B. bassiana* Bb115 strain (the most virulent, to date, against *Maruca vitrata*), the scientists were confronted with technical issues when attempting to detect *B. bassiana* mycelium directly form plant tissue, which has been reported with other strains on cereals in the literature. Project scientists have consequently initiated new collaborative links with the specialized Hochschule Geisenheim institute in Germany in the hope of overcoming this barrier.

Concurrently, project scientists have continued to investigate possible interactions between *B. bassiana* and the parasitoid *T. javanus* to assess if there is any negative impact when using both in the field. Adult parasitoids treated with the *B. bassiana* under laboratory conditions were not negatively affected in longevity and fecundity. However, dead adult parasitoids sporulated with conidia of *B. bassiana*, indicating a possible synergistic effect in the field. These experiments hold out the hope that an entomopathogenic fungus might be combined with a biocontrol agent for a synergistic impact on a pest population.

Last (third) larval stae of *Therophilus javanus* exiting the moribund *Maruca vitrata* caterpillar and feeding on it from the outside.

Objective 3. Scaling of solutions

When solutions have been developed, mechanisms are needed to deploy them cost effectively and sustainably for scaling; these mechanisms fall into three categories: 1. direct release into the environment and natural establishment, 2. educational, and 3. private sector and NGO involvement.

3.1.1. Maruca parasitoids (IITA)

In Benin, project scientists released almost 32,000 *Therophilus javanus* and 17,000 *Phanerotoma syleptae* (adult parasitic wasps), which work in synergy through two different modes, one as an ovo-larval parasitoid and the other a sturdier larval parasitoid that can detect *M. vitrata* caterpillars inside cowpea flowers and pods.

The parasitoids were released with the participation of local communities in six regions of Western Benin on patches of a wild alternative host for the pod borer, where the pest feeds and reproduces during the off season, ready to invade cowpea fields at the onset of the cropping season.

Scientists and members of local farming communities in Benin released parasitic wasps among the cowpea fields using collapsable release cages.

Preliminary field data indicated a good establishment by both biocontrol agents just a few months after their initial releases.

In conjunction with the releases, project scientists and collaborating organizations carried out practical training on releasing pod borer parasitoids and monitoring their establishment. Concurrently, they also conducted a sensitization campaigns with farming communities to explain the basic principles and rules of biological control and the release campaigns in their communities. In particular, farmers learned about the need to refrain from inappropriate use of chemical pesticides to preserve the newly released biocontrol agents.

Project scientists also initiated the same type of releases with INERA in Burkina Faso at several locations as part of a socioeconomic study. Eleven thousand *T. javanus* and 5000 *P. syleptae* were released on natural vegetation and in cowpea fields. Training and sensitization sessions with INERA technical staff and farming communities were also held.

Project scientists expect these parasitoids to establish on patches of wild vegetation where they were released and produce several generations of offspring, increasing the population and colonizing neighboring patches of host plants for *M. vitrata*. With the onset of the rainy season and the cowpea cropping seasons, the parasitoids will follow the *M. vitrata* populations migrating to cowpea fields. Scientists anticipate a

30 to 50 percent reduction of *M. vitrata* damage, depending on such local conditions as, rainfall patterns, planting dates, and cowpea varieties.

This effort is part of the overall IPM strategy for controlling cowpea pests that includes using resistant varieties and the judicious use of pesticides (eventually replaced with locally produced biopesticides) along with modern ICT (Information Communication Technology) approaches to empower low-literacy farmers to make informed decisions about pest control options.

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

Project scientists continued to supply adults and pupae of thrips parasitoids from Southern Benin to the INERA labs at Farokoba, Burkina Faso, for release on host plants with high populations of flower thrips.

3.1.3. Scaling of the neem and other virus control strategies (IITA, INRAN, and INERA)

Teaching farmers about the biocontrol release of parasitoids

Project scientists established demonstration plots in farmers' fields, targeting areas with high pest pressure; these plots reached more than 10,000 farmers. Results from last year's demonstration plots indicated significant variability across regions due to varying rainfall patterns, vegetation cover, and the cowpea varieties used by participating farmers. Data analysis is being finalized and the combination of the pod borer specific virus (MaviMNPV)and the emulsifiable neem oil mixture has been confirmed as performing well. This combination was also been confirmed by IITA trials in Kano, Northern Nigeria, under very high pod borer population pressure. Similar scaling field trials have also been conducted in Niger with 2,236 cowpea producers in 75 villages (225 sites) from 2014-2016, and in Burkina Faso.

3.1.4 Studies on the potential for use of biopesticides in the pest control market in Benin (IITA, MSU-SO4.1, INRAB, and UIUC)

In Benin, project scientists conducted two follow-up training sessions on the production of the pod borer virus by the women's groups at two localities in Benin (Dassa and Glazoue), with the aim of optimizing the workflow and assuring quality control. The sessions were held July 29 to August 12 in Dassa and July 15 to 27 in Glazoue, with 15 and eight participants, respectively (13 for clean *M. vitrata* production and 12 for the virus production). New *village rearing labs* were established for this purpose in each locality to ensure separating the virus production from that of healthy pod borer larvae.

3.2. Educational Solutions

Project scientists have developed ICT training materials, online and in-country ICT training for testing with current and potential partners, and FFF programs for testing of impact for scaling. Potential pathways for deployment of educational videos have been explored, and pathways to deploy videos have been tested. Pass-off of educational materials to NGOs and government agencies continued to be explored for scaling. The INRAN team has used neem and biocontrol animations in scaling sensitization projects. UIUC/MSU and IITA have project tested different animations against learning gains as compared to traditional extension. In all three cases, the animations outperformed the traditional extension talks in participants' learning gains. Efforts with farmers in Niger revealed the animations for biocontrol and neem sprays were highly effective in transmitting knowledge. The project is well-positioned to pass these materials to other groups that can integrate them into their educational programs.

A new lab for producing the *Maruca vitrata* virus has been established in a local village.

The project has ICT training packages and interfaces in development and ready for release to make our materials easily available to outside groups. An ICT training session was held in Ghana; four ICT training sessions were held online through Skype with local NGO groups in Ghana; and the SAWBO team has conducted ICT training sessions in Burkina Faso. More than 5000 *Extension Systems in Your Wallet*, a credit card style USB card containing SAWBO materials that users can keep in their wallet to share, have been distributed.

In August 16, 2016, SAWBO and all supporting materials and systems were legally transferred to Michigan State University.

Major Achievements

1. Neem and viral spray strategies have been brought forward into country-wide, large-scale field-testing with farmers.
2. Experimental analysis of field data has shown animated educational approaches to extension education to be as effective as the use of extension agent presentations for farmer attendees.
3. SAWBO has been able to demonstrate the potential for other organizations to scale their materials. We have released and tested an App that has the potential to make all of the SAWBO materials highly accessible and the use of the system highly scalable. This will serve at the basis for the development of the 2.0 version that we expect to release before the end of the project.

Human Resource and Institutional Capacity Development

Short-Term Training

ICT training on the use of SAWBO materials genotyping was conducted at Accra and Cape Coast by UIUC during spring/summer 2016 for 300 males and 300 females from Ghana.

Training of 68 males and 52 females in Burkina Faso and 50 males and 115 females was conducted online in Niger on the use of SAWBO materials, specifically animations, and in Ghana, Niger, Burkina Faso, Benin, and Nigeria by UIUC throughout 2016.

Technician Training

Online cross-training has been conducted to share skill sets among technical staff at INERA, INRAN, and IITA and to build upon previous technician-exchange programs. Cross-training revolved around scaling and deployment strategies.

Cross-Institutional Capacity Building for Biocontrol Agents

IITA, INERA, and INRAN are well positioned to continue to rear and to deploy biocontrol agents on a scale that we expect will significantly impact target pest populations in host country and to test, train, and scale the neem and virus strategy for pest control. We have begun to transfer this knowledge to our partners in Ghana at CRI and SARI. We have also moved to scaling the release of the biocontrol agents in Benin, Niger, and Burkina Faso.

Scholarly Accomplishments

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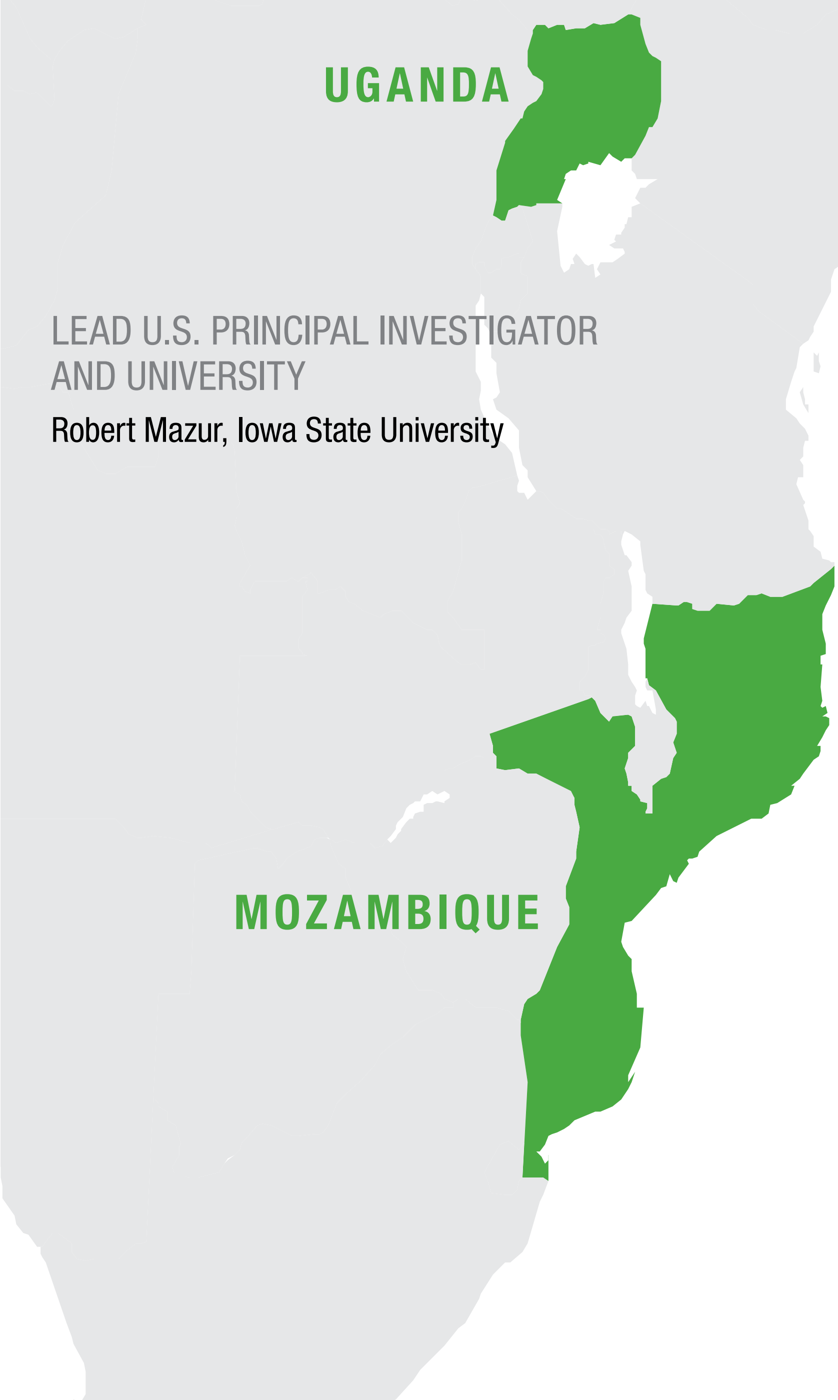
Farmer Decision Making Strategies for Improved Soil Fertility Management in Maize–Bean Production Systems

(SO2.1)



LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

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Abstract of Research and Capacity Strengthening Achievements

Researcher-led field experiments have been successfully completed in Uganda, with a third season of community-based field trials under way to enable farmers to learn about and test improved management practices and technologies, then evaluate, discuss, and decide on future actions. Two multistakeholder bean Innovation Platforms (IP) in Masaka and Rakai continue developing in membership size, diversity, enthusiasm, and capability, with more than 10 value-chain member organizations and more than 400 farmers.

Field experiments in Mozambique will be completed by mid-2017. The project team (led by IIAM), is collaborating with the Feed the Future SEMEAR project (led by IITA) and with CLUSA for community-based field trials. Fifteen project team members presented papers or posters at the Joint 2016 Pan-African Grain Legume and World Cowpea Conference.

Three MS students graduated from ISU, with MS students at collaborating institutions on track to graduate. Research results are being prepared for publication in peer-reviewed journals and dissemination in regional/national practitioner and policy outlets in Africa. Effective and efficient methods and media (animated video, etc.) for information dissemination to intermediate and end users have been developed and assessed in a participatory manner, and are being refined. Capacity strengthening through applied research-based training has been successfully conducted.

Project Problem Statement and Justification

Sustainable intensification of smallholder cropping systems requires both improved soil fertility management, in which legumes play an integral role, and enhanced capabilities among farmers to diagnose and to find solutions to important soil and other production constraints.

Project research activities focus on predominant soil types in key common bean production regions in the Masaka and Rakai districts in south-central Uganda and the Gurúè district in northern Mozambique. To understand potentially limiting soil characteristics and nutrient deficiencies, relevant analyses include physical and chemical properties of soil; nutrient omission studies; and researcher-managed field experiments. It is also valuable for researchers to understand local criteria and systems for characterizing soils, particularly those reflecting fertility versus deficiencies, and crops that are appropriate. The combination of scientific and local criteria will enhance understanding and sustainable implementation of recommended cropping system improvements.

Following field experiments, community-based field trials and demonstration sites facilitate farmer engagement in understanding key management practices and technologies recommended by researchers. Farmer field days stimulate interest through direct observation, participation, and comparison of site-specific management practices and technologies, which engage producers and other stakeholders in social learning, stimulate interest in the demonstrations and trials, and foster widespread use of management practices and technologies that prove successful in local conditions. The management practices and technologies include field preparation and measurement, seed selection, plant spacing, application of organic and inorganic fertilizers, weeding, postharvest handling, and farm business economic analysis.

An innovative communication and dissemination strategy integrates the use of radio, video animations delivered through smartphone technology, and print materials delivered by networks of partner organizations supplemented by field demonstrations and other participatory activities that engage farmers in widespread dissemination and adoption of appropriate diagnostic and decision support aids.

Objectives

1. Characterize smallholder farmers' motivations, current knowledge, and practices.
2. Develop and refine models about smallholder bean farmers' decision making.
3. Develop and validate diagnostic and decision support aids.
4. Develop and assess effectiveness of innovative approaches for dissemination.

Technical Research Progress

Objective 1: Characterize smallholder farmers' motivations, current knowledge, and practices.

Mozambique

In Gurúè, Mozambique, smallholder farmers produce their crops on several small plots of approximately equal size in different locations to maximize their yield and assess soil fertility by comparing the yields of seeds from the same source over two or more locations. Typically, they compare summit land farmed during the rainy season and bottom land, usually flood plain, farmed during the dry season.

Field day in Mozambique, with farmers examing their crops aand learning about the soil.

Farmers have actively participated in project field experiments that serve as the basis for field days to stimulate widespread interest through direct observation and comparison of site-specific management practices and technologies. Farmers have clearly indicated interest in trying new management practices and technologies to improve their crop yields. Those involved in project activities are willing to buy improved seeds, plant in rows, and apply fertilizer to their fields; most are already familiar with urea fertilizer. Farmers cited constraints related to access to extension services and capital, and labor if they increase the area planted to bean production. Farmers are reluctant to make significant changes in their production systems unless they result in reliable yield increases and they have access to reliable markets to increase their net revenues and improve their livelihoods.

Uganda

As found in the baseline study in 2014, farmers' decisions to adopt or adapt new management practices and technologies are influenced by awareness, availability, access, and affordability, and by their perceptions of key attributes, which include the relative advantage of a practice (locally available materials, multifunctionality of the practice, and relatively low cost of investment), observing a practice's success before adoption, compatibility with existing farm operations, and reduced complexity. Extension agents and farmer-to-farmer interactions are the most trusted information sources for improved soil fertility management.

More broadly, farmers' decisions are shaped by opportunities and incentives, and moderated by the level of resource ownership and access, labor hiring practices, market sales, and social and economic networks. Households with more adult laborers are significantly more likely to have purchased land which is in turn associated with manure application. Those with livestock have more fields and are more likely to use inorganic fertilizer. Most households, however, have few livestock, which limits manure availability, so the default is to purchase fertilizer.

Households that hire labor are significantly more likely to use manure and inorganic fertilizer, as well as pesticides and herbicides. They have more resources for a full range of inputs to achieve higher yields. Those who purchase inorganic fertilizers often have income from nonagricultural sources, savings, or available credit, and have borrowed in the preceding year. Households that expressed concern over security of land ownership or land use rights for bean and other crop production—approximately one-fourth in study communities in each country—were more likely to apply herbicides to ensure current season harvest.

Objective 2: Develop and refine models about smallholder bean farmers' decision making.

Uganda

Cleaning bean seed in Uganda

Smallholder farmers growing beans in Uganda's Masaka and Rakai districts use their resources to increase productivity, income, and natural resource integrity. Collective action and social learning are key elements. The two multistakeholder innovation platforms (IPs) established in these districts have been very active in promoting improved bean production. Researchers from Makerere University and National Agricultural Research Laboratories NARL continue to develop IP groups of farmers across the bean production value chain, including postharvest handling, marketing, and farmer organization skills. Innovation platforms comprise farmers, extension, a quality bean seed producer, input sellers, microfinance, and bean buyers. Members share interests, concerns, and strategies to address bean productivity and marketing constraints. IP farmer representatives pass on information to member farmers in their respective groups. Field trials and demonstrations accompanied by hands-on trainings by resource persons have strengthened human and social capital through experimental/experiential and peer-to-peer learning based on field observations to increase bean productivity and improve soil fertility. Following community-based training and experimentation, for example, some farmers invested in triple bags and jerry cans for storing their harvested beans.

In the first 2016 season, IP members in Masaka and Rakai hosted 18 field trials to demonstrate improved management practices and technologies for bean production and to assess the results. Having a full acre to demonstrate the various soil amendment field trials has proven very effective in attracting the interest of other farmers to raise questions and to learn. Additional field trials were conducted in Masaka and Rakai during the second 2016 season. Competitions organized by the project highlighted the most effectively managed field trial and demonstration, and the one that created the most interest in improved management practices and technologies among new learners.


Participatory review of decision support aids for farmers

Twenty-seven IP farmers received bean seeds under a contract farming arrangement for bean cultivation under CEDO (Community Enterprise Development Organization), a bean seed producing cooperative. Due to unusually low rains and high temperatures during the first season of 2016, more farmers began contract farming. More than 400 farmers opened accounts with IP partner MAMEDICOT (Masaka Microfinance and Development Cooperative Trust) to access loans to grow and market beans. A major benefit of the IP approach is farmers gaining access to the information, quality seed, inputs, and credit needed to produce beans.

Several organizations have initiated activities with the IPs, and some have expressed interest in joining as IP members. IP members have received training about the Kakasa (E-Verification) system designed to decrease counterfeit seeds and pesticides and increase agricultural yields. Supported by USAID's Feed the Future Uganda Agricultural Inputs Activity, Kakasa involves scratch code packaging labels containing a 14 or 16 digit verification number. Marketing agents explained their quantity and quality requirements. CIAT's precooked bean project is also arranging a bean grain market for farmers and will use radio to sensitize farmers on the program. The challenge is to fine tune the extension arrangements to support the farmers and the marketing strategies to efficiently reach the farmers with competitive price offers. Because all participants in the IPs have something to gain (farmers get more production, marketers get more quality beans to sell, dealers sell more inputs, CEDO contracts with farmers to get the quality seed it needs), the system is becoming self-sustaining.

In both Uganda and Mozambique, mapping indigenous soil classification with the scientific process has been initiated and included farmers and extension worker field-based classifications. Soil typologies are being documented and matched with scientific classification and commensurate management practices for bean production. Here we discuss the Ugandan results. The three predominant soils on the Buganda catena have differences and similarities in physical, chemical, and biological properties; however, apparently conflicting properties are sometimes cited within a given soil or horizon. This dichotomy can arise from management-induced soil changes that either increased or decreased erosion or deposition or mining of soil nutrients (table 1).

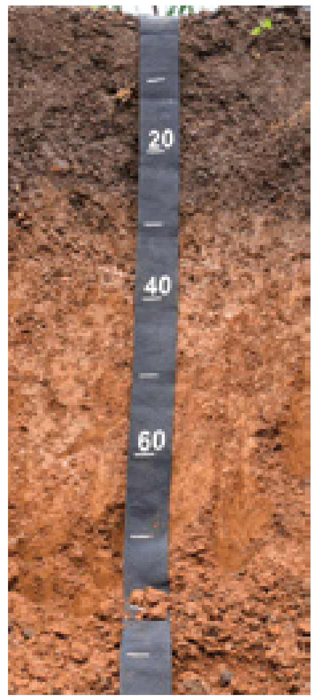
Soil fertility improvement is a function of soil fertility status, crop nutrient requirements, and available resources. Smallholder farmers and extension workers have had limited capacity to determine which nutrients to apply when and where based on indigenous soil types and existing soil maps.

Under the project, two approaches have been taken to improve farmer decision making in choice of nutrient amendments: refining farmers' indigenous soil classification system and refining existing scientific soil maps. The farmers' indigenous soil classification system has been improved by making it hierarchical and more elaborate. Results from the field experimentation can be more precisely applied to these soils. In regard to the refining of scientific soil maps, project scientists are in the advanced stages of deriving a Digital

Soil	Black	Red	Gravelly
Location In Figure 2	S6	S5	S4
USDA Soil Taxonomy Order	Alfisol/Ultisol	Ultisol/Oxisol	Inceptisol
Parent Material	Local sediments & pedisediments	Eroded pedisediment	Severely eroded pedisediment and basement rock
Landscape Position	Backslopes to toeslopes	Shoulders to upper backslopes	Summits and shoulders
Slope (%)	0 to 20	5 to 30	0 to 20
Drainage Class	Well	Well	Well
Profile Thickness Native	Thick	Moderate	Moderate
Profile Thickness Current	Thick or thin	Thin	Thin
A Horizon Thickness Native	Thick	Thick	Medium to thin
A Horizon Thickness Current	Thick or thin	Thin	Thin
Color A Horizon	Black	Reddish black	Reddish black
Color B Horizon	Red to brown	Red	Red
A Horizon Organic Matter	2 to 7%	1 to 5%	1 to 5%
Bulk Density Native A Hor.	Low	Medium	Low to Medium
Bulk Density Current A Hor.	Medium	High to very high	Medium to high
Bulk Density B Horizon	Medium	Medium to high	Medium to high
Texture A Horizon	Sandy loam or loam	Sandy loam or loam	Gravelly sandy loam or loamy sand
Texture B Horizon	Loam	Sandy loam or loam	Sandy loam to sand
Structure A Hor. Natural	Granular	Granular	Granular
Structure A Hor. Current	Granular to blocky to cloddy	Blocky to cloddy	Granular to blocky
Structure B Horizon	Blocky	Blocky	Blocky
Infiltration Current	Medium to high	Medium to low	Medium to high
Water Holding Capacity	Medium to high	Low to medium	Low
Ph A Hor. Well Managed	Slightly acid	Slightly acid	Slightly acid
Ph A Hor. Poorly Managed	Strongly acid	Strongly acid	Strongly acid
Biology Well Managed	Strong symbiosis	Moderate soil life	Moderate soil life
Biology Poorly Managed	Little soil life	Little soil life	Very little soil life

Table 1. Soils and prevalent properties given cropping histories, Buganda Catena near Masaka, Uganda. (In certain instances the Red Soil has been found to have columnar structure in the B horizon. In other places of the world, this often indicates a natric (sodium rich) horizon. It is unclear what it means in the Buganda Catena in the Masaka region of Uganda.)

Elevation Model based on catenary sequencing of hierarchical indigenous soil types. This will reduce cost, time, and resources in determining appropriate soil amendments by using results from field trials and tests of soils on a few farmers' fields using soil test kits.



Soil profile color and texture, Uganda

To promote adoption and use of recommendations, field trials and demonstrations are set up in strategic locations and farmer field days are organized. Field days are important methods for demonstrating management practices and technologies, attracting new farmers to try improved bean production and soil productivity recommendations.

Mozambique

In Gurúè, Mozambique, IIAM established a collaborative relationship with the Feed the Future SEMEAR program (Improved Seeds for Better Agriculture, 2015-2019), led by IITA (with CIAT, ICRISAT, and IIAM). SEMEAR uses a public-private partnership approach to disseminate improved legume seeds and complementary crop management practices already developed in Mozambique through the PARTI (Platform for Agriculture Research and Technology Innovation). The goals are as follows.

1. Increase the production and supply of breeder, prebasic, basic, and certified seeds.
2. Increase the adoption of improved technologies, income, and food security of more than 100,000 smallholder farm households in the Zambézia, Nampula, Manica, and Tete provinces.
3. Enhance national policy dialog on seed and fertilizer supply.

The SEMEAR – SO2.1 collaboration involves coordination of field trial and demonstration activities with communications materials and activities.

Objective 3: Develop and validate diagnostic and decision support aids.

Uganda

Soils in nearly all common bean fields in Masaka and Rakai, Uganda, are nutrient deficient. Field experiments documented that comparatively small additions of fertilizer (Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Zinc (Zn) resulted in more than doubling the common bean yield on black soil. Utilizing small amounts of Nitrogen (N) and P fertilizer with chicken manure, similar increases in common bean yield were documented by a project scientist. Through field research, preliminary fertilizer recommendations were developed for beans on different soils in Masaka and Rakai for black soil, red soil, and gravelly soil.

As farmers consider fertilizer recommendations from research, they also need to understand the economics of bean production. Most smallholder farmers rarely keep accurate records of farming inputs and other costs, such as land and family labor, nor do they achieve the best market prices for their beans. The project will continue to utilize research and data to educate farmers on price tracking and, relatedly, when and where to sell their beans.

Farmers have identified the three major activities associated with bean production to be labor costs, input costs, and postharvest handling. Input costs are the easiest to ascertain, whereas labor and land are only accounted for if hired or rented. Triangulation of cost data from scientist-led field experiments, community-based field trials, and individual farmers' plots, combined with the household survey, will be used to obtain a more accurate estimate of costs.

A model budget has been developed summarizing costs associated with one acre of bean production. Since the majority of farmers in our study intercrop, and beans are not necessarily the highest value crop, we have accounted for the value of other crops. We are working on a similar study for Mozambique. Preliminary results suggest farmers in some cases are realizing negative returns if all costs, including land and labor, are included.

Following completion of researcher-managed field experiments in Uganda, community-based field trials were initiated in early 2016 in Masaka and Rakai. Treatments included a control, organic only (chicken manure), inorganic only (DAP+urea), and a combination of organic and inorganic fertilizer. These were applied on the black, red, and gravelly soils following the recommendation for each soil type.

Results from 2016A (first) season showed that mean bean grain yields for the three soils were not significantly different. Fertilizer application significantly increased bean yield over the control. Mean grain yields for the organic, inorganic, or combination were not significantly different. Considering that 2016A was a moisture stressed season, these results show that manure application on the three soils was as good as the inorganic or a combination. Under such conditions, farmers can apply chicken manure (which is more readily available in their locality compared to inorganic fertilizers) at the recommended rate to improve bean yields. Field trials and demonstrations during the 2016B (second—August to December) season further tested these recommendations along with band versus broadcast application.

Beans planted in rows in Uganda (yellow control on left) to test different soils within a close area.

Planting common beans in rows, as done by a scientist in Masaka, impressed nearby farmers, leading them to adopt the practice in their own fields. All common bean field trial plots planted in collaboration with the Bean Innovation Platforms in Masaka and Rakai have been in rows. Farmers noted that although planting in rows required more time than their traditional scatter method, the time, effort, and efficacy of weeding; pest and disease monitoring and control; and harvest made their farming of beans much more efficient overall. Common bean stand density typically was about 10 plants m-2 in traditional scatter planting systems; project research documented that densities approaching 20 plants m-2 improved yield. Planting in rows and at higher density has occurred on black and red soils among farmers. Many farmers adopted even greater seeding rates that, when combined with high quality seed, are less efficient for seed cost and resource use. The research team noted that many farmers lack an accurate understanding of their field size, which makes calculation and application of recommended manure and fertilizer quantities problematic. Researchers are exploring methods to effectively address this situation.

Mozambique

Soil acidity is a major factor limiting bean production in red soils in the Gurúè district of Mozambique. Soil testing revealed potential soil acidity problems, with significant variation of soil pH among communities and within sites. The project's lime incubation study estimated that 3.0 to 3.5 mg ha-1 of limestone were needed to ameliorate the pH level for beans.

A field in Mozambique being harvested

Soil pH in some paddy-rice production systems of Mepuagíua precludes good growth and yield of common bean. To assess bean response to limestone and fertilizer on paddy rice soil, the project conducted an experiment with four treatments:

1. control (no limestone or fertilizer added)
2. limestone added at three ton ha-1
3. fertilizer (20 kg N ha-1, 35 kg P_2O_5 ha^{-1}, 12 kg K_2O ha^{-1}, 10 kg S ha^{-1}, and 0.5 B + 2.5 Zn kg ha^{-1} [NPKSZnB])
4. fertilizer and limestone, as in treatments two and three

Use of limestone alone significantly increased bean grain yield from 1,420 kg ha^{-1} (control) to 2,160 kg ha^{-1} with lime. The combination of limestone and fertilizer NPKSZnB provided mean bean yield above 2,700 kg ha^{-1}—nearly double the control yield. Bean yield response was greater for limestone alone than for the fertilizer treatment alone.

During the 2016 rainy season in Mozambique, the project conducted an experiment on soils in the upper topographic position in Mepuagíua to improve soil phosphorus availability with local rock phosphate and nitrogen (through use of pigeonpea) before planting bean and to expand the bean growing area by increasing productivity on soils previously not considered suitable for common bean. Available P levels are exceptionally low in soils of Mepuagíua. The use of pigeonpea in the season before planting bean rotation provided an opportunity to test the recently characterized Evate rock phosphate of Nampula province while also providing increased nitrogen availability for the subsequent bean crop. Triple super phosphate (TSP) was included as a comparison with the Evate rock phosphate.

Results confirm the need for phosphate inputs for pigeonpea and indicate that the phosphate needs were substantial, requiring approximately 20 kg P ha^{-1} as TSP to reach maximum yield. Figure 1 also indicates that the Evate rock phosphate, in this specific crop–soil combination was surprisingly effective, providing a maximum yield of approximately 1,000 kg pigeonpea grain ha^{-1}, with an application of 80 kg ha^{-1} of total P added as Evate rock phosphate. The maximum yield with the addition of soluble phosphate was about 1200 kg pigeonpea grain ha^{-1}—much higher than expected. Common bean will be planted on these plots in January 2017.

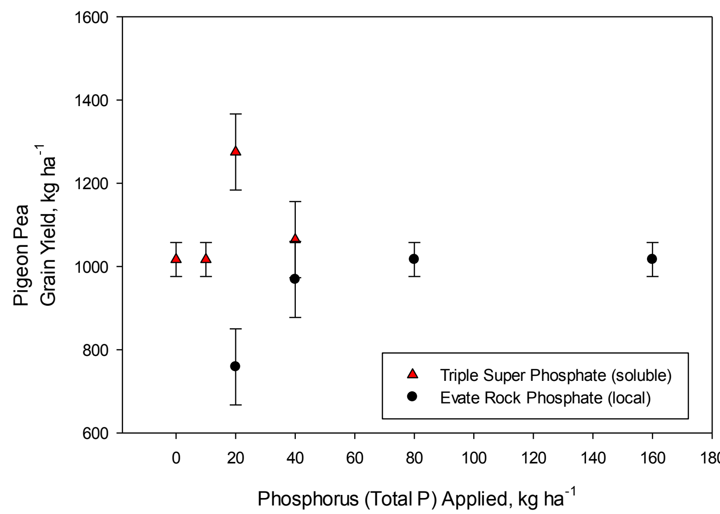


Figure 1. Response of pigeon pea grain yield to evate rock phosphate and soluble fertilizer phosphate (TSP).

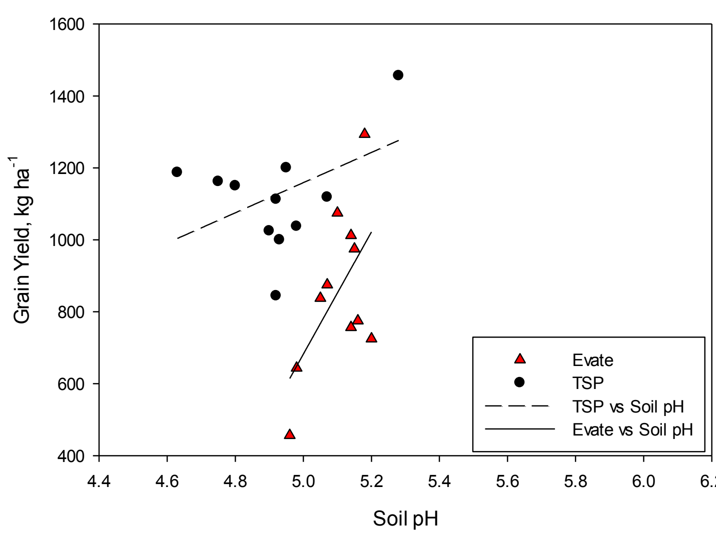


Figure 2. Increase in pigeon pea grain yield where soil ph increased, mepuagíua 2016

There was a clear grain yield increase with increased soil pH (figure 2). The 1200 kg ha^{-1} pigeonpea yields during this unusually dry year document an excellent potential for pigeonpea to provide grain and a crop for future study.

Consistent with AGRA's suggested protocol for identifying nutrient response, an eight-treatment experiment was conducted to identify critical nutrients for varieties recently released by IIAM's breeding program. These red clay and black-with-high-clay-content soils proved responsive to N, P, K, and S (sulfur) fertilizers. The highest yield had N, P, K, S, and Zn added. Lack of rain in the dry season significantly impacted nutrient uptake and bean yield.

Soils in Gurúè vary over space and time. Good soil management strategies for maintaining soil productivity require understanding physical, chemical, and biological properties; soil clustering (classification) criteria; and key farmers' indicators of soil quality. The project trained Mozambican research and extension personnel in Gurúè in spatial data collection and how to conduct farmer interviews to determine their knowledge of soils, soil classification and management, soil sampling, and soil profile description. Farmers from Invacula, Hulane, and Mepuagíua-Sede villages discussed soil classification. A transect walk along catenae was taken to assess soil and other physical features and infrastructure.

Soils were sampled along a toposequence by individual farmers for focus group discussions about their properties, suitability for crops, and risk management strategies. Three soil profiles 150 cm along the toposequence were described and soil samples from different horizons were collected for laboratory analyses and soil classification. Farmers' perceptions revealed three different observable transition models along toposequence in Mepuagia (see figure 3).

1. red clay, black with low clay content, black with high clay
2. black with low clay content, sandy with light color, black with high clay content
3. black with low clay content, black with low clay content, black with high clay content

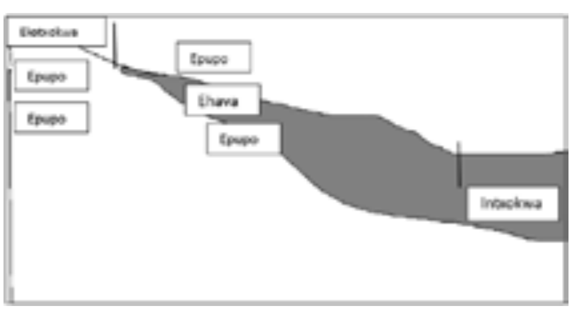


Figure 3. Dominant Soil along a Toposequence in Mepuagíua

Farmers in Gurúè distinguish different soil types (color, texture, stoniness) and their relationship with the toposequence. Their experiential knowledge enables them to match crops with soils, taking into account fertility and water demands of crops. In *Intxokwa* soil (black with relatively high clay content), the major crops are rice, beans, maize, vegetables, and sugarcane. In the top slope, the dominant soil is *Ekotxokwa* (red with clay), for which major crops are sorghum, pigeonpea, cowpea, bambara nut, cassava, sweet potato, sesame, soybean, and maize. Farmers share knowledge about variety, adaptability, and soil suitability for a given crop.

Objective 4: Develop and assess effectiveness of innovative approaches for dissemination

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

Project scientists have tested Innovation Platform (IP) groups in Masaka and Rakai in Uganda to assess farmer reactions to messages regarding bean production. IP farmers, with guidance from project staff, have also conducted their own farmer-managed field trials in multiple locations. From these test results, IP farmers have reached informed decisions on which new methods of bean production are most appropriate and valuable for them.

Crop review in Uganda based on earlier trainings with project scientists

For 2017, an animated video message is being developed by SAWBO as a result of project activities focused on research-based recommendations for growing beans. Principal recommendations include: (1) soil testing for acidic soils; (2) use of quality seed; (3) increased density of planting; (4) use of a single seed per hole if seed is quality assured or certified; (5) row planting; (6) three weedings; and (7) use of chicken manure as fertilizer. This animation will also be in the local languages of farmers in both Uganda and Mozambique.

In both Uganda and Mozambique, NGO partners have been recruited to help evaluate the effectiveness of this SAWBO animated video. In Uganda, CEDO has agreed to help the project evaluate the video by showing it through CEDO's network of farmer-trainers. This will reach thousands of farmers in the area, and the CEDO training system gathers evaluation feedback using mobile devices. In Mozambique, CLUSA has agreed to show the SAWBO animated videos to its bean producing farmers in a similar way to gather their reactions and input. Additional participatory sharing and feedback is being developed with IITA and other projects in the area.

Major Achievements

- The field experiments in Uganda have been completed, and the third season of community-based field trials (n=27) that enable farmers to learn about, test, and discuss improved management practices and technologies are being conducted.
- Our two multistakeholder bean Innovation Platforms in Masaka and Rakai continue to develop in membership, diversity, enthusiasm, and capability, and as formal organizations, with a growing list of value chain member organizations (10+) and farmers (400+).
- In Mozambique, the project team (led by IIAM), has established a working relationship with the Feed the Future SEMEAR project (led by IITA) and CLUSA to collaborate in community-based field trials that will enable farmers to learn about and test improved management practices and technologies, and discuss together.
- Research results identify soil acidity as a major constraint to cropping beans in red soils in the Gurúè district, so project work has conducted trials to investigate treatments to address soil acidity.
- Our analyses of weekly market prices and patterns, along with detailed costs of inputs, is contributing to refined development of decision support aids and training.
- Effective and efficient methods and media for information dissemination to intermediate and end users have been developed and assessed in a participatory manner; they are being refined.

Human Resource and Institutional Capacity Development

Short-Term Training

There were four types of short-term training activities implement by the project.

1. **Innovation Platform training**: 37 events, 1088 females and 863 males trained in Masaka and Rakai, Uganda. Training provided by MAK, NARL, CEDO, MAMEDICOT, Agrodealers, ISU, UIUC, MSU, UC-Davis, and Kilimo Trust.

The project used the Innovation Platform approach to conduct short trainings with extension agents and farmers, including crop management practices such as soil classification and characterization, aspects of planting, pesticide use, seed selection and processing, harvesting of beans, and pest identification. Additional training subjects were use of biogas, agrochemical handling, and precooking of beans. It also included organizational aspects (formation of cooperatives, strategic planning for private sector coordination, handling and marketing).

2. **Training on Agrotechnology of Bean Production and Postharvest Handling**: various days, 21 females and 57 males, Gurúè, Mozambique, conducted by Institute of Agricultural Research of Mozambique in partnership with Center for Interdisciplinary Studies and Development (CEID).

This short-term training engaged farmers on a range of issues to strengthen farmers' knowledge on best agronomic practices, including soil and pest management. The training included extension demonstration, farmer discussion, and PowerPoint and animated video presentation

3. **Promotion of Soil Fertility Management**: Summary of Soil Health Research Findings: class presentation to 23 females and 47 males, Gurúè, Mozambique, conducted by Institute of Agricultural Research of Mozambique in partnership with Center for Interdisciplinary Studies and Development (CEID).

This training covered the results of research, including fertilizer use computation and communication strategy for farmers.

4. **Training on soil profile description, interview technique for capturing soil information, soil sampling strategies and coding.** Training in classroom and in field for collaborators, three females and six males, Gurúè, Mozambique, conducted by Institute of Agricultural Research of Mozambique.

This training was designed to build skills among collaborating partners on soil data gathering and record keeping for soils description and classification.

Long-Term Training

The project has funded long-term degree training for six African students, one female and five males. Three students are studying in the United States, at Iowa State University and the University of Hawaii and the other three are studying at Makerere University.

Research Capacity Strengthening Funding

Institutional Capacity Strengthening grants focused on combining indigenous and scientific knowledge of soils and recording, analyzing, and interpreting GIS associated data with biophysical, economic, and social data. They also involved training scientists, technicians, students, and district staff in GIS and geospatial skills for distinguishing toposequencing, chronosequencing, and lithosequencing of soil catena. Trainees acquired practical skills and detailed understanding of soil variability along selected landscapes of the catena using characteristics identified locally by farmers and relating it to modern scientific approaches.

Trainees developed practical skills to enhance farmer decision making for soil fertility management by combining indigenous and modern scientific soil classification practices. This activity assists in understanding and documenting the importance of geomorphology and topography of soils and their importance in farmers' classification of soils in project villages.

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 short-term training, 1,135 women and 973 men have benefitted and one woman is benefitting from long-term training.

Scholarly Accomplishments

Goettsch, L. H., Lenssen, A.W., Yost, R. S., Luvaga, E. S., Semalulu, O., Tenywa, M., & Mazur, R. E. Improved production systems for common bean on Phaeozem soil in south-central Uganda. *African Journal of Agricultural Research* 11(46): 4796-4809. DOI: 10.5897/AJAR2016.11760.

Bwambale, N., Mazur, R., & Abbott, E. (2016). Adoption of Integrated soil fertility management in Central Uganda: Influence of perceived practice characteristics and socioeconomic factors. Pan-African Grain Legume and World Cowpea Conference, Livingstone, Zambia, February 28 to March 4.

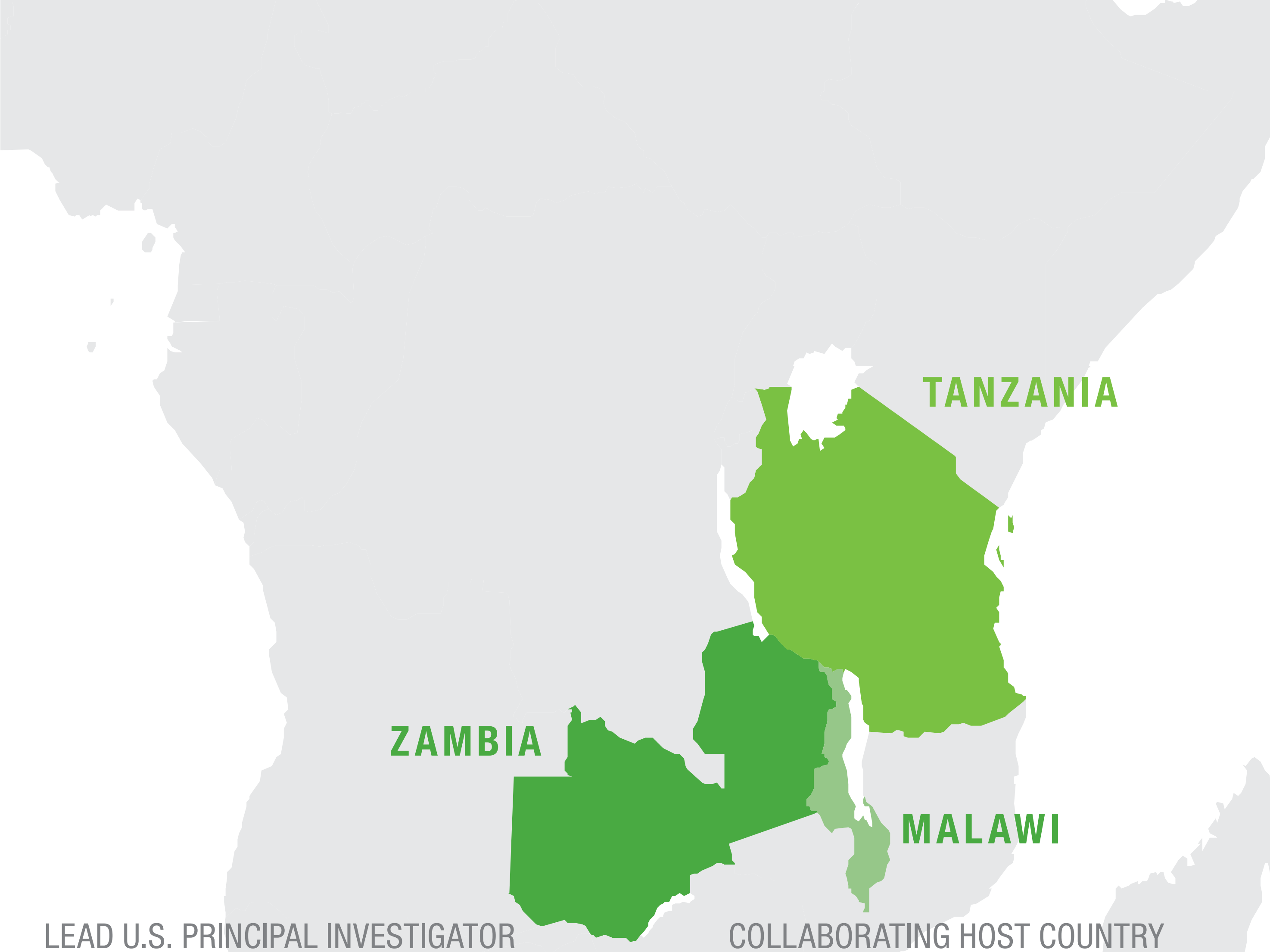
Kyebogola, S., Semalulu, O., Tenywa, M., Lenssen, A., & Mazur, R. (2016). Effect of integrating organic with inorganic fertilizers on bean yield on three contrasting soils. Pan-African Grain Legume and World Cowpea Conference, Livingstone, Zambia, February 28 to March 4.

Kyomuhendo, P., Tenywa, M., Semalulu, O., Lenssen, A., Yost, R., & Mazur, R. (2016). Limiting nutrients for bean production on three contrasting soils in Uganda. Pan-African Grain Legume and World Cowpea Conference, Livingstone, Zambia, February 28 to March 4.

Semalulu, O., Tenywa, M., Yost, R., Mazur, R., Luswata, C., Kyebogola, S., Kabango, F., & Smith, C. (2016). Comparison of the Indigenous Soil Classification System with the FAO and Soil Taxonomy Systems. Pan-African Grain Legume and World Cowpea Conference, Livingstone, Zambia, February 28 to March 4.

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

(SO2.2)



LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

Vincent Amanor-Boadu, Kansas State University

COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

Lawrence Mapemba, Lilongwe University of Agriculture and Natural Resources, Malawi

Fredy Kilima, Sokoine University of Agriculture, Tanzania

Gelson Tembo, University of Zambia

Kara Ross, Kansas State University

Allen Featherstone, Kansas State University

Abstract of Research and Capacity Strengthening Achievements

Project researchers developed an innovative approach to assessing the relative positions of food groups in food hierarchies, which helps in developing the most appropriate private and public strategies for enhancing consumption of particular foods. They also identified the bean products of choice in Malawi, Tanzania, and Zambia, allowing us to provide the bean supply chain with the information to enhance overall chain performance.

This information on food preferences will help breeders focus on developing products with the appropriate characteristics and attributes for their target populations; other food producers will gain knowledge of production quantities, based on the markets in which they are operating. The combination of knowing the particular position of a food product in a particular food hierarchy along with consumers' preferences regarding that food becomes critical information for improving production and marketing decisions to enhance incomes and reduce poverty.

Over the program's life, the project has supported 22 graduate students from partner countries and has contributed to enhancing the decision-making and management capacity of various industry stakeholders, especially farmers and traders.

The foundation laid by our work should continue to help industry associations in Malawi improve their organizational performance and help breeders integrate more into the upstream supply chain and contribute to farmers leveraging their resources to achieve desired economic objectives. Finally, with the direct support of the Feed the Future Legume Innovation Lab, we were able to provide research and publication training to Lilongwe University of Agriculture and Natural Resources' (LUANAR) faculty and students. Beneficiaries and benefits of the project include:

- More than 1,250 industry stakeholders, of whom about 40 percent are female
- Twenty-two graduate students (12 male and 10 female) in Malawi, Tanzania, and Zambia. Four of these students recently graduated.
- Five undergraduate students in Zambia
- Three two-day industry capacity enhancing workshops focused on supply chain governance and competitiveness in Malawi, Tanzania, and Zambia
- Seven one-day workshops on enhancing the performance of beans through hands-on value-innovation training in Malawi (four) and Zambia (three)
- Three industry workshops and focus group engagements in Tanzania
- Two national conferences in Malawi and Zambia
- One two-day workshop on research and publishing capacity enhancement at LUANAR, Malawi

Project Problem Statement and Justification

Grain legumes are not traditional staples in Zambia, Malawi, and Tanzania, which means they are not priority crops for policy makers, breeders, traders, or regulators. But they are priority crops for the many farmers and traders who produce and sell them. To improve the supply chain for grain legumes, and the lives of their farmers and traders, requires developing an improved understanding of how consumers make their food-buying decisions. Additionally, an appreciation of the factors that support these decisions could provide insight into how policy makers and the grain legume trade develop public policies and business strategies. Such an understanding could enhance the contribution of grain legumes to overall economic progress. Additionally, given the health and nutritional benefits of grain legumes, identifying specific strategies to improve their consumption could contribute to improving the overall health of the populations in these countries and potentially reduce their health budgets. These results could then be scaled into other countries with similar population profiles to achieve similar results.

Against this background, the primary problem this research project sought to address was an innovative approach to understanding the factors that influence and shape consumers' food choices in Malawi, Tanzania, and Zambia. Project goals also include identifying the bean varieties of choice in these countries to inform the breeding activities of bean breeders, helping them to enhance the performance of the whole supply chain, not just producers.

We organized the project into three integrated parts:

1. Development of an empirical foundation for understanding the position of legumes in the food hierarchy and the factors that could improve this position
2. Employing the results to identify opportunities for enhancing the position of legumes in the food hierarchy in each country
3. Working directly with the legume trade and its supporters to develop individual and collective processes to take advantage of the knowledge generated from the research to enhance their individual and collective economic performances

The countries of Zambia, Malawi, and Tanzania are representative of 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. It will provide insight into 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 collected primary data in three countries and employed statistical and discrete choice experiment methods to complete objective one. Statistical methods were used to construct a food hierarchy for the six major food groups in Malawi, Tanzania, and Zambia. Knowing where legumes fall on the food hierarchy would help assess the challenges associated with altering consumption habits to improve demand for legumes. A discrete choice experiment was used to identify the relative importance of the different characteristics of beans in the selected countries. The purpose of this experiment was to identify the relative importance of different bean characteristics to consumers, by which to inform breeding-to-market strategies to enhance total chain economic performance.

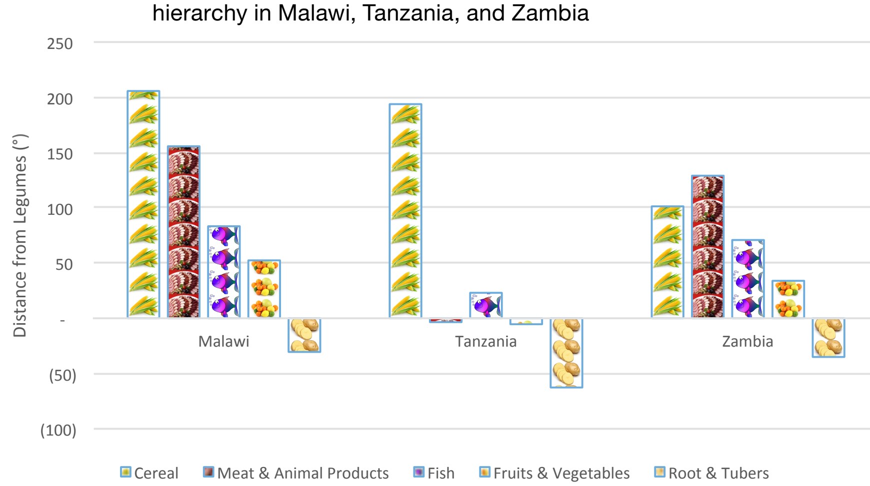
Results

Virtually all respondents in all three countries consume beans at home, away from home, or both. In Malawi and Zambia, about 78 percent consumed them solely at home and 22 percent consumed them both at home and away from home. Only a small fraction of consumers indicated consuming beans only when they were away from home. At 33 percent, a larger proportion of Tanzanians consume beans both at home and away from home compared to the other two countries, and a smaller proportion (65 percent) consumed beans solely at home.

Legumes' position in the food hierarchy in each of the three countries was determined in relation to five other food groups: roots and tubers; fish; meat and animal products; cereals; and fruits and vegetables. To establish positions, we used the per capita share of food budget allocated to each food group and the food group's criticality to the household's food and nutrition security. Research results show that legumes sat on the second rung from the bottom, ahead of roots and vegetables, in Malawi and Zambia, but on the fourth rung from bottom in Tanzania, ahead of roots and tubers, fruits and vegetables, and meat and animal products. We surveyed about 680 people in Malawi, 740 in Tanzania, and 841 in Zambia to conduct the primary analysis.

Knowing legume's position in the hierarchy was not, however, enough; we also need to know how far it was from the other food groups. We described the percentage difference between legumes' rung score and that of the other food groups as distance measured in degrees. The distance of the different food groups from legumes in the three countries are presented in figure 1. The figure shows very different pattern in the relative distance across the countries, suggesting the need for unique strategies to enhance legumes' position in the food hierarchy in each country. Estimated Kendall's Coefficient of Concordance for each of the countries confirms that there is no statistically significant concordance among the rankings of the food groups in any of the three countries. This further underscores the importance of pursuing different strategies to enhance legumes' position in the food hierarchy in each of these countries.

Figure 1. Distance of food groups from legumes in the food hierarchy in Malawi, Tanzania, and Zambia



We identified color, grain size, cooking time, and gravy quality as the critical attributes of interest to consumers through expert, trader, retailer, and consumer interviews in Malawi, Tanzania, and Zambia. In each country, we identified the top four colors and categorized grain size into large, medium, and small; cooking time into fast and slow; and gravy quality into good and poor. The foregoing attribute levels yielded 48 (4 x 3 x 2 x 2) combinations or hypothetical products from which we created six unique choice sets, each with eight hypothetical products. The sample in each country was divided into six and each subsample presented with one of these choice sets.

Respondents were then asked to allocate a fixed budget among their eight selected choices. This experiment revealed consumers' stated preferences for the different product offerings, allowing us to obtain information on desired bean grain characteristics in each country.

Malawi consumers generally preferred fast-cooking, medium-size, red mottled beans with good quality gravy. In Tanzania, the standard preference across all product offerings was fast-cooking, medium-size *Njano* beans, with good gravy quality. A fast-cooking large-size purple bean (*Kablengeti*) with good gravy quality is the preferred bean product in Zambia.

Across all three countries, consumers were more flexible with the color and size of their beans than they were with cooking time and quality gravy, which had to be fast and good, respectively. Presenting consumers with a budget constraint accentuated their preferences for these non-negotiable product characteristics. We learned that breeders would do well to select for cooking time and gravy quality if they want to build value innovation across the supply chain.

Roadside bean market in northern Malawi Photo. credit: Vincent Amanor-Boadu

It was prudent to identify the individuals in the household who made decision on the purchasing of beans as well as those cooking the beans when trying to enhance legumes' position on the food hierarchy. In Zambia, while almost 80 percent of respondents indicated that they were solely responsible for deciding to purchase beans, 40 percent of respondents indicated that their spouses influenced bean purchases compared to 10 percent indicating children. Similar distributions were found in Tanzania, with the main difference in spousal influence, which was about 25 percent with children's about 18 percent. Spousal and children's influence in bean purchases in Malawi was close to 50 percent and more than 20 percent, respectively. Any initiatives to influence increased bean consumption, based on surveys, should focus on adults in the households, with spouses also recognized as important participants.

Male-headed households allocated a statistically significant higher per capita share of their food budget to legumes in Zambia and Malawi, but gender had no impact in Tanzania, nor did a higher education level.

Expenditure is a product of quantity and price. Given that prices of the same product could differ because of the relative bargaining power of the participants in the exchange at any time, we have chosen not to disaggregate expenditure. We hypothesized that legume expenditures would be determined by respondents' gender, age, household size, income in quintiles, education in categories (none, primary, secondary, technical/vocational, and university/college), expenditure on other food groups, and the types of food legumes were paired with. The statistically significant factors influencing the legume expenditures in the three countries are as follows:

- Household size was statistically significant in all three countries. Expenditure on legumes increased by 0.46 percent in Tanzania, 0.23 percent in Zambia, and 0.25 percent in Malawi.
- Being separated or divorced or widowed decreased expenditure on legumes in Malawi by about MWK 1,200. (equal to $1.65; $1.00 = 727 Malawian Kwacha). Conversely, in Tanzania, expenditures were TSH 8,848.24 ($3.95) less than households with singles. Marital status had no effect on legume expenditure.
- While the third and fourth income quintiles in Malawi exhibited a statistically significant increase in legume expenditure over the first quintile, the second and the fifth were not statistically different. Income by quintiles had no effect on legume expenditures in Zambia.

Cooking time and gravy quality are important determinants of consumer preference in some regions, so if beans are to sell successfully in the market, farmers must be taught what types and qualities their potential customers value and want to buy.

- In Malawi, part-time employment was not statistically different from unemployed respondents; however, full-time salaried and self-employed people increased legume expenditures in both Malawi and Tanzania.
- Age had a small but positive effect on legume expenditure in Malawi; conversely, age was not significant in Tanzania and Zambia.
- A percentage increase in root crops' expenditures increased legume expenditure by 0.18 percent in Zambia. In Tanzania, a percentage increase in cereal and root crops expenditures increased legume expenditures by 0.30 percent and 0.09 percent, respectively. In Malawi, a percentage increase in fish and cereals expenditures increased legume expenditures by 0.10 percent and 0.13 percent, respectively.
- In Malawi, households that paired beans with plantains or bananas spent MWK 669.58 more on legumes than those who did not. No other food pairing presented a statistically significant coefficient. No paired food group presented a statistically significant relationship with legume expenditure in Tanzania and Zambia.

This information suggests some strategic initiatives that may be used to improve legume expenditures, such as consumers' willingness to pay higher prices, consume more, or both. Policies and marketing efforts must focus on larger households in all three countries and on households headed by older people in Malawi. The extent of complementarity in Tanzania between cereals and legumes is higher than in the other countries. This could be because legumes as an accompaniment to the staple maize has not been discovered in Zambia and Malawi. Recipe education initiatives on TV and other visual media could help address this challenge. In Malawi, it is important that alternative starches, such as plantains and bananas, be incorporated into these recipes, since the results suggest a positive pairing effect with legumes.

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

Approaches and Methods

The project used secondary data available from the World Bank and the Food and Agriculture Organization of the United Nations to explore the production and marketing/distribution situation for beans in Malawi, Tanzania, and Zambia, using trend analyses and econometric analyses as the analytical tools. The datasets used for Malawi and Tanzania were the World Bank's nationally-representative Living Standards Measurement Survey – Integrated Survey on Agriculture (LSMS-ISA) and the Food Security Research Project (FSRP) dataset for Zambia.

Results

Zambia's bean production is the lowest among the three countries and has remained virtually flat over the past decade, probably due to Zambia's lowest per capita consumption of beans among the three countries, about a quarter to a third of what prevails in the region. In Malawi, consumption is the principal driver of production. On the other hand, bean production in both Malawi and Tanzania have been increasing since the turn of the century at an average annual rate of about 7.3 percent and 6.5 percent. Although Malawi's production of 58,277 MT was only about 10.7 percent that of Tanzania's in 2000, it had increased to nearly 17 percent by 2014, with Malawi producing nearly 190,000 MT.

This trend in Malawi has been supported by price increases and significant organization of farmers into horizontal alliances. For example, the Grain and Legume Association (GALA) has organized more than 200,000 farmers into associations and farmer cooperatives that are working on facilitating input procurement and product sales. Such development has not been pursued in Tanzania. These farmers have increased the land planted to beans from under 144,000 ha in 2000 to almost 330,000 ha by 2014. They have also benefited from yield improvement, but not as dramatically as harvested area, about 41 percent over the same period. The improvements in area and yield in Tanzania were comparatively smaller, 68.7 percent and 22.3 percent, respectively, between 2000 and 2014.

Because of low production in Zambia, much less is known about downstream activities in Zambia's bean industry compared to Malawi and Tanzania. Project work has shown that traders are not only important in the supply chain, but their business and demographic characteristics influence prices. Research showed that the market where traders operate in Zambia influenced the types of beans sold and the prices received, which illuminates how these traders engage with farmers upstream in their supply chain and influence how much they can afford to pay in their bean procurement decisions.

Although product handling and its effect on quality and price has not received much attention in the regional bean industry, damaged beans create about a 10 percent discount in Zambia. Traders and retailers sort beans manually to improve the quality presented to the consumer. In some cases, they sorted beans by color, one grain at a time, with the view of achieving a superior presentation.

The work in this area is currently ongoing, with graduate students in Kansas State University, Lilongwe University of Agriculture and Natural Resources, and Sokoine Agricultural University pursuing their degrees and working on 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.

The most important component of this project is disseminating the knowledge so it can be used to change behavior or influence decisions. As a result, this project has maintained a close relationship with producers and their downstream partners in Malawi, Tanzania, and, Zambia. Because of the strength of local partnerships in Malawi, the project was more successful in penetrating local industry and building closer ties for capacity development. For example, developing a closer relationship with the Grain and Legume Association (GALA) in Malawi was critical in facilitating direct access to producers and their customers. Over the life of the project, more than 1,250 farmers and their downstream partners in capacity building and information sharing activities were engaged. About 40 percent of the participants were females. We did these engagements through hosting 16 workshops in all three countries and two national conferences in Malawi and Zambia.

Major Achievements

- We have determined how far beans are from the center of the plate, so private and public policy makers can now develop appropriate policies and strategies to move beans and other legumes to the center of plate to enhance their contribution to the health of their customers and populations and improve the incomes of the upstream bean and legume supply chain.
- We discovered that bean grain size, color, gravy quality, and cooking time were important determinants of consumer preference. Our work now involves engaging breeders to help them appreciate *Breeding for Supply Chain Performance*, an initiative that uses consumer preference information to develop varieties that increase the financial performance of all stakeholders at the different stages in the supply chain in different markets.
- Held the first national conference on beans as a strategic crop for wealth and health in Malawi and Zambia.
- Built strong industry relationships with project investigators in host countries.

Human Resource and Institutional Capacity Development

Short-Term Training

- One-day workshop on nurturing supply chain relationships in Malawi, Tanzania, and Zambia
- One-day workshop on new product development to enhance overall supply chain performance in Malawi, Tanzania, and Zambia
- One one-day workshop on farmer organizational structures in Malawi
- Three one-day workshops on supply chain relationships to enhance the role of beans in health and wealth creation in Malawi and Zambia
- Three two-day workshops to build capacity on supply chain relationships for lowering costs and increasing value in Tanzania
- One national conference on Beans for Health and Wealth in Malawi and Zambia

Long-Term Training

Twenty-two graduate students were supported for long-term training under this project. The majority of students are being trained at the host country institutions of LUANAR and Sokoine Agricultural University. Four of the trainees are in the Masters in Agribusiness program at KSU. We also supported research engagement and training for five undergraduates at the University of Zambia. Of the 22 graduate students, 12 are male and 10 female.

Research Capacity Strengthening Funds

Training on Scientific Research and Publications
KSU faculty led this special short-term training session for 60 faculty and graduate students at Lilongwe University of Agriculture and Natural Resources on research ethics and the publication process.

Achievement of Gender Equity Goals

The project has consciously endeavored to attain gender equity in all its activities. Ten of the 22 graduate students supported by the program are female and about 500 of the more than 1,250 participants in our industry engagement and capacity-building programs are female. More than 87, 85, and 82 percent of consumers interviewed in Tanzania, Malawi, and Zambia, respectively, were female. Virtually all traders we engaged formally were female.

Students from all three of the host countries—Malawi, Tanzania, and Zambia—have pursued undergraduate and graduate degrees connected to the project, some at Kansas State University, like this student, above.

Training students is one of the objectives of this project.

Scholarly Accomplishments

Chengula, O., Kilima, F. T. M., Amanor-Boadu, V., & Ross, K. October 2016 Commercialization of Bean Production in Tanzania. Sokoine University of Agriculture, School of Agricultural Economics and Agribusiness Studies, Department of Agricultural Economics and Agribusiness.

Chilala, C. and Tembo, G. October 2016 Factors Affecting Bean Prices Received by Smallholder Farmers in Zambia. University of Zambia, School of Agricultural Sciences, Department of Agricultural Economics and Extension. Policy Brief.

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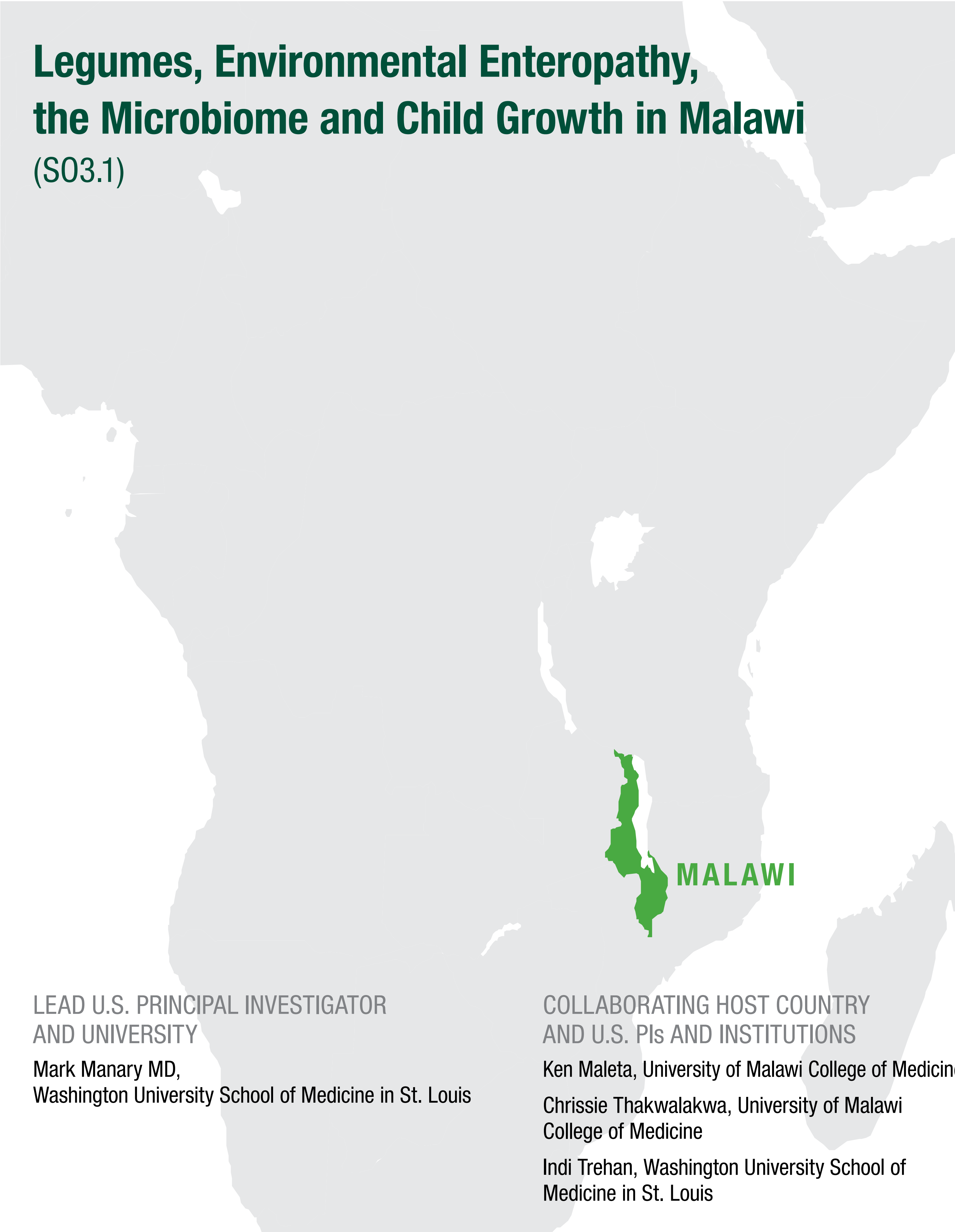
Tembo, G. and Mwiinga, M. October 2016. Determinants of beans consumption among households in Lusaka district. University of Zambia, School of Agricultural Sciences, Department of Agricultural Economics and Extension. Policy Brief.

Tumeo, M., Mapemba, L., Amanor-Boadu, V., Ross, K., & Edriss, A-K. 2016. Consumer Choice of Dry Common Beans in Malawi: Case of Lilongwe City. Lilongwe University of Agriculture and Natural Resources (LUANAR). Policy Brief.

As the mother looks on, a child in Malawi is weighed, measured, and given a health exam by one of the project's team members as part of the *Legumes, Environmental Enteropathy, the Microbiome and Child Growth in Malawi* project.

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

(SO3.1)



LEAD U.S. PRINCIPAL INVESTIGATOR AND UNIVERSITY

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Washington University School of Medicine in St. Louis

COLLABORATING HOST COUNTRY AND U.S. PIs AND INSTITUTIONS

Ken Maleta, University of Malawi College of Medicine

Chrissie Thakwalakwa, University of Malawi College of Medicine

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

Abstract of Research and Capacity Strengthening Achievements

Environmental enteric dysfunction (EED) is a pervasive, chronic subclinical gut inflammatory condition that places rural children at high risk for malabsorption, stunting, and acute malnutrition. Researchers are conducting two randomized, controlled clinical trials, one for children 6-11 months, the other for children 12-35 months, to investigate the effect of both common bean and cowpea consumption on infant and toddler growth and gut health. Palatable complementary foods for the feeding studies were developed locally.

A mother waits in the shade with her infant for her child evaluation at the program's medical station.

The project has completed sample collections for Study 1 on infants 6-11 months old who received complementary foods with cowpea, common bean, or locally standard foods (maize). In December 2016, samples were sent to the University of California, San Diego, for sequencing and analysis. Study 2 continues with 12-35-month-old children and follows them for 12 months with or without legume interventions.

One hundred percent enrollment was achieved in Study 1 and complete enrollment and sample collection was achieved for Study 2. Results of the impact of interventions on stunting and other characteristics will only be available after samples are analyzed and compared to other data collected on weight, height, and other variables.

Powdered versions of the three types of supplemental foods for children in each study: common bean, cowpea, or maize.

The local team implementing the clinical trial continued ongoing training in the principles of Good Clinical Practice. The operational manual developed under the project is the basis for implementation of the clinical trials. Two Malawian doctoral students enrolled at the University of Malawi College of Medicine were identified and began work on the project. Short-term training included a value chain-based food safety course for 41 people and field research training for village health workers and College of Medicine staff.

Project Problem Statement and Justification

Minimizing EED is an essential step in improving the survival and growth of at-risk children. EED is characterized by T-cell infiltration of the intestinal mucosa, leading to a chronic inflammatory state with increased intestinal permeability, translocation of microbes, nutrient malabsorption, poor weight gain, stunted physical and cognitive development, frequent enteric infections, and decreased response to enteric vaccines. EED often begins to develop shortly after the transition away from exclusive breastfeeding and increases progressively during the first several years of life, a high-risk period marked by mixed feeding with complementary foods to the complete reliance on adult foods for sustenance.

One of the project's technicians prepares a bowl of legume based cereal for feeding to toddlers and younger children.

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, two different grain legume-based foods are being tested as complementary food products because their protein content is significantly greater than that in 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 grain legume flours at scale, if they prove to be successful in reducing EED and stunting.

In Malawi, project researchers, with the contributions of local staff, have developed complementary foods for feeding infants—as they transition from breast feeding—that are based on locally available cowpea and common bean-based flours.

The Manual of Operations provides very specific guidelines on all data collection, including the collection of biological samples.

In the first of two randomized, controlled clinical trials, the researchers are evaluating the effect of feeding cowpea, common bean, or standard complementary food to infants 6-11 months old. The second trial enrolls 12-35 month-old children and follows them for 12 months with or without legume interventions.

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.
3. Complete preparations to initiate study aim 1, 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 Operations*, which provides the fieldwork directives for the field team, continued to be followed. Developed by Chrissie Thakwalakwa with input from 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 reporting procedures for any unexpected and adverse events.

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

The cowpea- and common bean-based flour recipes were used in the clinical trials during 2016. LUANAR (Lilongwe University of Agriculture and Natural Resources) graduate students developed these grain legume-based recipes earlier in the project in accordance with WHO specifications. Their recipes underwent acceptability testing in Malawian infants with the support of the Malawi College of Medicine, with the most appealing and nutritious selected for use in Study 1 and Study 2.

Objective 3: Complete preparations to initiate study aim 1, including staff recruitment, training, and community engagement and organization.

One hundred percent enrollment and more than 50 percent of sample collection for Study 1 and 100 percent completion of sample collection for Study 2 was achieved in FY 2016.

Mothers wait with their infants for the regular testing connected with the project.

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 provides overall supervision of the field studies.

LUANAR master's degree students developed the food recipes, and now one student continues to be engaged in the clinical trial, supervising bean sourcing, flour production, preparation, and safety monitoring of the intervention foods.

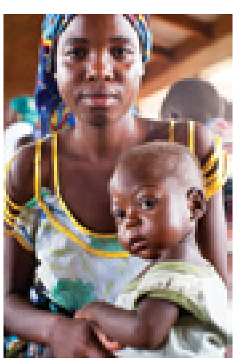
Major Achievements

1. The project researchers have attained 100 percent enrollment in Study 1 and 100 percent sample collection in Study 2, with strong and continued local collaboration.
2. Project researchers developed the materials and conducted a Food Safety Seminar at University of Malawi College of Medicine, with 10 speakers and 41 people trained.

Human Resource and Institutional Capacity Development

Research Capacity Strengthening

The PI and the research team continued to promote sustainable research through relationships with the Malawi College of Medicine and colleagues at LUANAR. The training was provided to the four Malawian graduate students continued to develop them into investigators able to to to continue research on addressing and preventing childhood malnutrition, especially through the use of grain legumes.


A mother waits with her infant to be enrolled in the program.

Chrissie Thakwalakwa of the College of Medicine, with support from Drs. Manary, Trehan, and Maleta, 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. One of the two students from the Agriculture Department at LUANAR, who was engaged in developing the formulations and recipes using cowpeas and common beans, continued to supervise the production and quality control of the flours using the food science and safety knowledge she obtained through her training. The two Malawian PhD students are attending classes at Washington University in St. Louis (WUSL) that are not offered at the University of Malawi to increase their research knowledge. These students were also trained in dPCR lab techniques at WUSL.


Part of the project support team during a clinic day

Short-Term Training

Staff Field Training
The University of Malawi College of Medicine conducted field training with six female nurses, four male drivers, and 15 village health workers (11 men and four women) in study guidelines, anthropometric data collection, biological sample collection, and community engagement. The nurses and drivers were from the University of Malawi College of Medicine; the village health workers are employed by the Ministry of Health.

Short-Term Training: Food Safety
The University of Malawi College of Medicine conducted a one-week training course for 22 males and 19 females on food safety to explore the key threats to legumes and other Malawian crops across the value chain.

Long-Term Training

Two PhD candidates are studying at the University of Malawi College of Medicine for PhD degrees in epidemiology (one male and one female), while another two students are studying food science and technology for MS degrees at LUANAR. One student continues her PhD training in community health with Tampere University (Finland), based in Malawi. This student provides leadership in the fieldwork as part of her training.

Achievement of Gender Equity Goals

Findings from these studies will benefit both women and men, including parents and children. Improvements in child health are most likely to benefit women in Malawi, since they have the primary role in childrearing. Health improvements that lead to improved survival and intellectual development of girls will also translate into improved school performance and career capacity.

All but one of our Malawian graduate students is female. Both American graduate students are female. One of our nondegree American students is female.

Particular care was extended to women for inclusion in the Food Safety training course, with approximately 46 percent of attendees female.

A health post in Malawi where mothers bring their infants and young children for regular tests and to pick up the food provided to study participants.

Scholarly Accomplishments

Divala, O., Stephenson, K., Agapova, S., Kaimila, Y., Thakwalakwa, C., Trehan, I., Maleta, K., & Manary, M. (2016). Impact of legumes vs. corn-soy flour on environmental enteric dysfunction and stunting in rural Malawian children. Presentation at the Pan-Africa Grain Legume and World Cowpea Conference, Livingstone, Zambia. February 27-March 4.

Healthy bean pods

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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Dieudonne Ilboudo, Institut de l'Environnement et des Recherches Agricoles (INERA)

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

Abstract of Research Achievements and Impacts

An assessment of the climbing bean/maize intercropping production system was completed in the highlands of Guatemala in collaboration with the Feed the Future Legume Innovation Lab SO1.A1 *Genetic Improvement of Middle-American Climbing Beans for Guatemala* project team.

A research activity was initiated using existing data to build an evidence base by exploring pathways through which legumes could potentially enhance agriculture and food security linkages. Analyses using nationally representative data from Zambia suggests consistent positive effects of cereal–legume rotation and other legume technologies on net crop income, calorie and protein production, and months of adequate household food provisioning.

Several research studies on sustainable seed systems were initiated or completed, including two studies on *willingness to pay* for different types of seeds--one in northern Tanzania (for beans) and the other in northern Ghana (for cowpea).

A case study, ASK, focused on a farmer association in Burkina Faso, was completed. ASK provides a good example of how a farmer-based local seed entrepreneurship model can be combined with nongovernmental quality control oversight to produce quality declared seed (QDS). This study also points to the challenges of smallholder farmers' ability to grow seed that meets quality standards, despite technical training and supervision from ASK and the need for lowering the QDS price, so that it remains attractive to a seed producer as a business but still falls within the 30 to 40 percent range of grain price to remain affordable within the average range of farmers' willingness to pay. The case study and the willingness-to-pay experiments indicate that increasing the yield of cowpea seed that meets quality standards is central to lowering the price of seed while keeping it profitable for seed producers to grow.

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 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 (MO) achieve two important goals—accountability and learning. Greater accountability (and strategic validation) is a prerequisite for continued financial support from USAID and better learning is crucial for improving the effectiveness of development projects and ensuring that the lessons from experience—both positive and negative—are heeded. Integrating this culture of impact assessment into publicly funded programs, such as the Feed the Future Legume Innovation Lab, will help increase the 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

Analysis of Baseline Study in Guatemala

Rationale. The indigenous population living in Guatemala's western highlands is among the most undernourished in the world. Beans, which are one of the best sources of nutrients, are commonly grown in this region as part of the *milpa* system, a traditional system of intercropping maize and beans (or other crops). The crops are either planted concurrently or staggered, with maize planted first and beans a few weeks later. Research indicates that to tackle the problem of undernourishment, household consumption of self-produced beans can be significantly enhanced by increasing bean yields. *Genetic Improvement of Middle-American Climbing Beans for Guatemala* is a LIL project led by NDSU.

To better understand the current status of the climbing bean/maize intercropping production system and to establish a baseline about production of climbing beans in the highlands of Guatemala, a study was designed by this project team, *Genetic Improvement of Climbing Black Beans for the Highlands of Central America.*

Method. A survey of more than 500 farm households from the five departments in Guatemala (Chimaltenango, Quiché, Huehuetenango, San Marcos, and Quetzaltenango) representing the highland bean growing regions (and not land at least 1500 meters above sea level) was conducted in 2015, for which data cleaning and analysis was completed in 2016. Data were collected from an average of six randomly selected farm households from 87 villages across these departments.

A project collaborator conducts a survey on the importance of beans to Guatemalan farmers in the western highlands and the use of the intercropping system.

Results. The results indicate the importance of beans in the diets of the indigenous population and confirm the need for increasing productivity to enhance bean security in the region. Major findings are summarized below.

<u>Bean Consumption</u>

- The majority of farmers (80 percent) do not sell beans; only six percent sold more than 50 percent of their harvest.
- Self-production covered less than half of annual bean consumption for 23 percent of farmers; self-production covered 50-75 percent of annual consumption for 33 percent of farmers. After self-produced beans were consumed, 50 percent of farmers purchased beans at least weekly.
- On average, a household cooked beans 2.5 times and consumed a total of five cups of (uncooked) beans in the week prior to the survey.
- Households with children under 14 served beans to the children an average of three days in the week preceding the interview. On days that children ate beans, more households served beans at breakfast (75 percent) and dinner (79 percent) than at lunch (53 percent).
- Beans are consumed throughout the year; consumption is highest at or after the harvest—from November to March—and lowest in July and August (Figure 1)

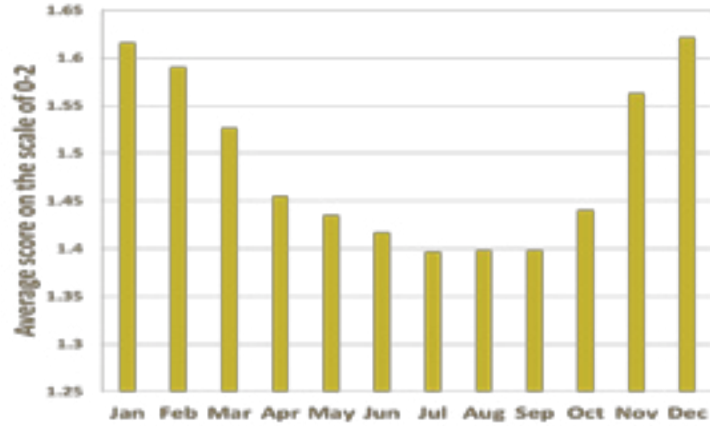

Figure 1. Mean bean consumption score over the past 12 months on a scale of 0 (no consumption) to 2 (relatively more consumption). Source: Baseline survey of bean farmers in highlands of Guatemala (2015)

Dietary diversity, culinary preferences and farmers' perceived nutritional value of beans

- On average, a household consumed six out of 12 diverse food groups in the day prior to the survey; more than 85 percent reported consuming beans the previous day.
- Frijol Negro, Vulgaris, and Bolonillo were among the most preferred bean varieties for consumption named by farmers
- Respondents indicated that flavor (76 percent) was what farmers like most about a bean variety followed by thickness of bean broth (32 percent), cooking time (3.2 percent), expansion of size (1.5 percent), and color retention during cooking (0.7 percent).
- On a scale of 0-10, farmers rated beans 8.9 in terms of nutritional value, which was just below the score for maize (9.4) but higher than the perceived nutritional value of rice (8.1), potatoes (7.8), meat (6.9), chayote (5.9), and Coca-Cola (1.4).

Bean Productivity and Production Practices

In 2016, the project team used existing data to build an evidence base by exploring pathways through which legumes could potentially enhance agriculture–food security linkages. Specifically, researchers examined the links between the ways in which households incorporated legumes into their cropping activities (e.g., cereal–legume rotations, cereal–legume intercropping, legume monocropping, or intercropping legumes with noncereal crops) and several indicators of household food security and welfare along the agricultural production and income pathways. The legumes commonly grown in Zambia and included in the study are groundnuts, soybeans, mixed beans, cowpeas, velvet beans, and bambara nuts. The cereals considered for cereal–legume rotation and intercropping are maize, sorghum, and millet.

Data. The data for this study are from the Rural Agricultural Livelihoods Survey (RALS), a two-wave, nationally representative panel survey of Zambian smallholder farm households conducted from June to July 2012 and 2015 by the Indaba Agricultural Policy Research Institute. The RALS data include detailed information on household demographics, crop, crop sales, asset holdings, and access and distances to agricultural extension. From these data, we compute net crop income, defined here as the gross value of crop production minus fertilizer costs. Both RALS survey waves also capture households' months of adequate household food provisions, and the 2015 wave included a household dietary diversity score (HDDS) module. These data allow us to analyze the effects of legume technologies on five household-level welfare indicators: net crop income, calories produced/capita/day, protein produced/capita/day, Months of Adequate Household Food Provisions (MAHFP), and Household Dietary Diversity Score (HDDS).

Because we are interested in how incorporating legumes into cropping activities affects cereal-growing households, the analytical sample consisted of all panel households that grew a cereal crop in the 2010/2011 and 2013/2014 agricultural seasons (N=6,226).

Empirical strategy. The project team relied on observational data on the adoption of legume technologies and household welfare and thus employed quasi-experimental techniques to identify the welfare effects of cereal–legume intercropping and rotation and other legume combinations.

For all outcome variables except for HDDS, we estimate household fixed effects (FE) models of the welfare indicators regressed on measures of the household's adoption of the various legume technologies (cereal–legume intercropping, cereal–legume rotation, and other legume technologies) and a vector of control variables. Adoption of the various legume technologies is measured as either (i) a binary treatment variable equal to one if the household practiced the legume technology on at least one plot and equal to zero otherwise; or (ii) a continuous treatment variable equal to the household's total hectares under the legume technology.

Given the count-variable nature of the MAHFP and HDDS, we also attempted to estimate correlated random effects negative binomial (CRE-NB) models for these outcome variables. But unfortunately, the CRE-NB model did not converge for MAHFP. For HDDS, we estimated linear CRE and CRE-NB models in which the RALS 2015 HDDS is regressed on the RALS 2015 levels of the co-variates as well as the RALS 2012 and 2015 household time averages of the co-variates.

Finally, for all outcome variables, we estimated two-stage least squares (2SLS) regressions in which we instrument for the three main explanatory variables of interest, which we suspect may be endogenous to household welfare: adoption of cereal–legume intercropping, of cereal–legume rotation, and of other legume technologies.

Results. Legume cultivation is fairly common among cereal-growing smallholder households in Zambia. Approximately 64 percent of such households grow legumes in some way. Among legume crops, groundnuts are the most popular (53 perent of households), followed by mixed beans (17 percent), soybeans (8 percent), and Bambara nuts and cowpeas (3 percent); just 0.1 percent of households grew velvet beans. The most common way that Zambian smallholder farmers incorporate legumes into their farms is via rotation with cereals; approximately 40-43 percent of households do this each year. In contrast, cereal–legume intercropping is practiced by less than five percent of households each year. Approximately 22-23 percent of households grow legumes via other means (e.g., legume monocropping).

The econometric analysis results are summarized in table 1 and indicate that cereal–legume intercropping exhibits few statistically significant (p<0.10) effects on the outcome variables examined in this study. Only for HDDS do we find statistically significant effects that are retained across multiple non-OLS estimators. The results suggest positive and statistically significant cereal–legume intercropping effects on HDDS in three of eight models.

<table>
<tr><th></th><th colspan="3">Main Explanatory of Interest</th></tr>
<tr><th>Outcome Variables</th><th>Cereal-Legume Intercropping</th><th>Cereal-Legume Rotation</th><th>Other Legume Technologies</th></tr>
<tr><td>Net crop income</td><td rowspan="4">Little evidence of sts. sig. effects once use 2SLS/FE</td><td rowspan="4" colspan="2">Consistent (+) effects for continuous measure of adoption</td></tr>
<tr><td>Calorie production</td></tr>
<tr><td>Protein production</td></tr>
<tr><td>MAHFP</td></tr>
<tr><td>HDDS</td><td>Some evidence of (+) effect (3/8 models)</td><td>Some evidence of (+) effect (4/8 models)</td><td>(+) in most (6/8 models)</td></tr>
</table>

Table 1. Effect of legume technologies on household income, calorie and protein production, Months of Adequate Household Food Provisioning, and Household Dietary Diversity Score

In contrast to cereal–legume intercropping, cereal–legume rotation has more statistically significant, and generally positive, effects on household welfare (table 1). The results are not robust to the choice of estimator for HDDS, but for MAHFP, calorie production, and protein production, the majority of the estimates suggest that cereal–legume rotation positively affects these outcome variables. The fixed effects results, for example, suggest that MAHFP increases by an average of 0.05 units with the use of cereal–legume rotation, and by an average of an additional 0.05 units given a one-hectare increase in cereal–legume rotations.

The positive effects of cereal–legume rotation on MAHFP appear to be coming mainly through the food production pathway, as cereal–legume rotation significantly increases both household calorie and protein production but has mixed effects on household crop income (table 1). The FE results suggest that each additional hectare of cereal–legume rotated land increases calorie production by an average of 1,088 calories/capita/day and protein production by an average of 38 grams/capita/day, holding other factors constant. These are substantial increases vis-à-vis the sample means of 5,913 calories/capita/day and 158 grams of protein/capita/day.

In summary, cereal–legume rotation appears to have generally positive effects on household food access (especially MAHFP) and on per capita calorie and protein production. These effects appear to come through both the crop income pathway and the agricultural production pathway. From a policy perspective, the empirical evidence that cereal–legume rotations can improve food production and food access among Zambian smallholder cereal growers, points to the need to promote this practice where it is feasible for farmers.

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. One of the important factors that determines the sustainability of a seed system is whether the effective 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 bean grain. Also, complying with the country's seed regulatory requirements to be able to sell the seeds labeled and packaged as certified seed or quality declared seed (QDS) increases the cost and 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 improved varieties, 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, especially for self-pollinating crops like beans.

Keeping the genetics constant, the viability of a seed market depends on the co-existence of the following demand and supply side conditions (two of each):

1. Whether farmers are able to perceive the seed product as a quality planting material
2. Given the perceived quality difference, whether they are willing to pay a premium price for seed compared to grain price
3. Whether the price farmers are willing to pay is high enough to recover the cost of producing the quality seed
4. Whether the quantity and frequency of seed demanded at that price is large enough to attract suppliers to produce and sell quality seed

Researchers conducting group discussions with a community seed bank

There are no rigorous studies that have examined these demand and supply side dynamics in a systematic manner. The following two activities were thus conducted:

1. assessment of the willingness of smallholder farmers to pay for quality seed and
2. a case study on a community-based-seed system attempt to address these demand and supply-side research questions in the context of dry grain legumes.

Willingness of smallholder farmers to pay for quality seed

This study was conducted in Tanzania for beans in collaboration with SUA and CIAT, and in Ghana for cowpeas in collaboration with SARI. In Ghana all the fieldwork and data collection has been completed but data entry and analysis are still ongoing. In Tanzania the study was concluded in 2016.

Rationale. In Tanzania, 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 seeds (*QDS*), and recycled seeds saved from farmers' own harvested grain. These four types of planting materials differ in seed input (i.e., which generation of seed is used to produce them), the regulatory supervision they receive or do not receive, and technical conditions under which they are produced. The empirical questions addressed by this study are whether 1. the cost differential across these types of seeds makes them qualitatively different products as reflected in their perceived or actual performance of the plant and 2. that translates into the differential price that farmers are willing to pay for these seeds.

Farmers observing cowpea seed trials prior to participating in a willingness to pay bidding auction experiment

Method. A two-step approach was used to address the two research questions. First, double-blind field experiments were established in 12 hamlets across two districts in the Kilimanjaro region of northern Tanzania. The demonstration plots (FEs) were used to illustrate the value of planting *certified 1* versus *certified 2* versus *QDS* versus *recycled seed* of the bean variety, *Jesca*, so farmers could see first-hand the difference in agronomic plant performance, the potential harvest, and the bean quality. Second, once farmers observed how different types of seeds of a particular variety performed, experimental bidding auctions were conducted to learn how much farmers were willing to pay for these seeds based on the observed differences in performance.

The FEs were planted on an approximately 100 sq. m. subplot with a total plot of 400 sq. m of land. All farmers living in the village were invited to field days to see the bean plots and learn about their performance. The first field day was conducted around the flowering stage (or soon after), and the second field day occurred just before or after harvest. Attendees at the first field day were given a sheet where they ranked the subplots according to a set of criteria agreed upon by the farmers as a group. 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 Bidding Experimental Auctions (BEA) were conducted to determine how much farmers were willing to pay for the different types of seeds during the second field day in October 2015. Farmers were told that one of the four auctions will 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 TS 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 reveals the premium (or discount) due to the different seed type attributes (*QDS* vs. *certified 1* vs. *certified 2* vs. *recycled*). 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 incentive compatible with regards to eliciting true farmer WTP.

A total of 245 farmers participated in the BEA across the 12 villages. Survey data were collected from each farmer that participated in the auction experiment to capture their socioeconomic household characteristics and experience with producing beans, varietal use, and prior use of different types of seed.

Results. This study on farmers' willingness to pay for quality seed has generated three interesting results that have implications on designing seed systems for legume crops. First, seed quality matters (not just the genetics). Certified seed 1 (Type A) consistently outperformed certified seed 2 (Type B) and quality declared seeds (QDS) (Type D). QDS outperformed farmer recycled seeds (Type C) of the same variety in field experiments conducted on farmers' fields; farmers' perception of these quality difference was highly correlated with the yield performance as reflected in their ratings of different plots during the flowering and harvest stages (figure 2).

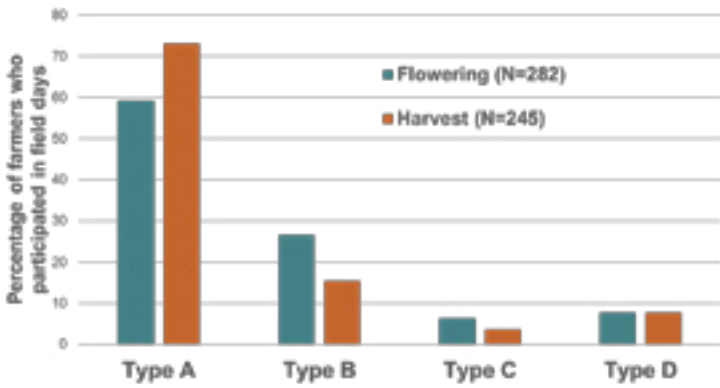

Figure 2. Farmers' rating of the best plot at two stages: Results from Tanzania

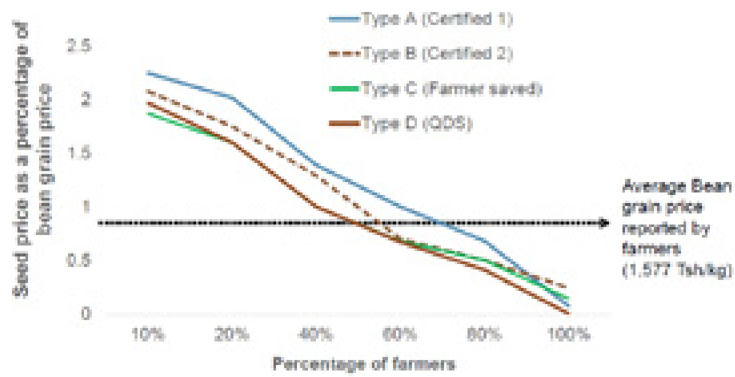

Figure 4. Farmer willingness to pay for seed of different perceived quality as a percentage of bean grain price: Results from Tanzania

Second, all else equal, farmers are willing to pay premium for quality seeds. The relative difference in Farmers' WTP for different seed types is correlated with the relative difference in their perceived quality differences (figure 3).

Figure 3. Comparison of farmers willingness to pay with their perceived quality differences (N=247)

Third, results confirm the downward sloping demand curve for quality seed—the number of farmers willing to pay a premium price for quality seed declines as price of seed increases (figure 4).

The overall implication of these findings is that there is no one-size-fits-all strategy to meet the seed needs of all the farmers. The strategy should be built on multipronged approaches based on subsidies to meet the needs of farmers on the lower end of the WTP spectrum, private sector-based approaches to meet the needs of farmers on the higher end of the WTP spectrum, and alternative models based on in-kind subsidy and not-for-profit seed production models (e.g., community-based models) for farmers in the middle ranges

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

The problem of lack of farmer access to legume seed has left millions of smallholder farmers relying on their own or other farmers' harvested grain (accessed from the local market) as the main source for seed. The advantages of this decentralized informal seed system is that it is able to meet diverse needs of farmers at lower cost (i.e., at grain price); however, the informal system is not directly linked with the research system and thus not able to quickly channel new improved varieties and produces lower quality seed, which negatively impacts the productivity of food production.

A graduate student from the research team conducting a farmer interview

Method. The case study used a combination of qualitative and quantitative methods comprised of a) Key informant interviews (KII) conducted in 2015 and 2016 with the staff members of the ASK management team, INERA, the National Seed Service (SNS), the Union Nationale des Production Semenciers (UNPS) and other farmer organizations that purchased seeds from ASK; and b) Survey conducted in 2015 of 225 cowpea farmers across 25 villages where ASK is active, including ASK member seed producers (53), nonseed producers (99), and nonmembers (73).

Results. In terms of the evidence of use of purchased seed, 70 percent of ASK members and 30 percent of nonmembers had purchased seed from ASK in the past. However, the average farmer last purchased seed three years ago. Despite the presence of ASK, saved seed remains the major source of planting material. Only 35 percent of cowpea plots surveyed were reported as planted to an improved variety (IV).

The case of ASK provides a good example of how a farmer-based local seed entrepreneurship model can be combined with a nongovernmental oversight of quality control to produce QDS. The broad-based services provided by ASK to its members is highly valued and is the reason for its long-term operation. But despite their operation, access to new varieties and affordable quality seeds of cowpea in ASK member communities remains a constraint as evidenced by:

- Low adoption of improved varieties: 30-40 percent of plots planted to IV
- Low cowpea grain and seed yields: average 300 kg/ha
- High rejection rate: 30 percent of seed is rejected (according to farmer survey)
- High price of seed set by ASK: more than double the grain price

Reliance on the subsidized seed distribution channel. More than one-third of seed produced by ASK members ends up being sold outside the ASK network, which ends up being distributed as free or highly subsidized QDS (i.e., 95 percent of certified seed ends up in this channel), which undermines the overall sustainability of the model.

In summary, this case study's results indicate the ongoing challenges of smallholder farmers' to grow seeds that meet quality standards despite technical training and supervision from ASK. It points to the need for lowering the price of QDS that is still attractive to a seed producer to remain in the seed business but is within the 30–50 percent range of grain price. Increasing the yield of cowpea seed that meets quality standards is key to lowering the price of seed while still making it profitable for small-scale, community-based seed producers.

Major Achievements

Research conducted in Zambia suggests consistent positive effects of cereal–legume rotation and other legume technologies on net crop income, calorie and protein production, and months of adequate household food provisioning.

Scholarly Accomplishments

Maredia, M., Ilboudo, D., & Pitoro, R. (2016). The economics of community-based seed production: A case study of the Association Song Koaadba (ASK), Burkina Faso. Poster presented at the Pan-African Grain Legume and World Cowpea Conference, Livingston, Zambia, February 28 to March 4.

Maredia, M., Shupp, R., Mishili, F., Reyes, B., & Kusolwa, P. (2016). Farmer willingness to pay for quality bean seed: Experimental evidence from Tanzania. Paper presented at the Pan-African Grain Legume Conference, Livingston, Zambia, February 28–March 4.

Legume Innovation Lab
Human and Institutional Capacity Development

FY 2016 Summary Report

Legume Scholars

The Feed the Future Legume Innovation Lab established the Legume Scholars Program in 2014 with two partners, the Feed the Future Innovation Lab for Collaborative Research on Peanuts and Mycotoxin Management and the CGIAR's Research Program on Grain Legumes. The combined programs obligated a total of $1,250,000 to support the program. The key objectives are to enhance the relationships among researchers in the CG Centers, U.S. universities, and host country institutions while training a new cadre of young scientists.

The first and only group of scholars to date includes three women and two men, all PhD candidates. Each candidate is in the midst of his or her PhD program and focusing heavily on course work and qualifying exams. With their advisors, they are developing research plans; the Feed the Future Legume Innovation Lab will be able to share more information on those research plans in the next annual report, when the students have solidified their areas of study and specific research projects.

The students, their research project plans, and mentors/project directors are as follows:

1. **Ms. Rosemary Bulyaba (Uganda)** is in the Agronomy Department at Iowa State University under Dr. Andrew Lenssen, investigating the integrated crop management of common bean. CGIAR scientist Dr. Waswa Boaz of CIAT has been tentatively identified as the counterpart in the research program.

2. **Mr. Aggrey Gama (Ghana)** is in the Food Science and Technology Department at the University of Georgia, working with Dr. Koushik Adhikari and investigating groundnut value addition and safety. For the CGIAR, Dr. Rhoda Zulu of CIAT/Malawi will be collaborating with Aggrey and Dr. Adhikari.

3. **Ms. Pacem Kotchofa (Benin)** is in the Department of Agricultural Economics at Kansas State University, working with Dr. Vincent Amanor-Boadu. She is investigating the cowpea value chain. Dr. Ousmane Coulibaly, IITA grain legume research scientist, will be co-supervising Ms. Kotchofa's doctoral research.

4. **Ms. Susan Mokongu Moenga (Kenya)** is in the Plant Biology Department at the University of California, Davis, working under Dr. Douglas Cook and investigating drought resilience of chickpea. Dr. Vincent Vadez of ICRISAT is the CG scientist who will collaborate with this research.

5. **Mr. Isaac Osei-Bonsu (Ghana)** is in the Plant Biology Department at Michigan State University under Dr. David Kramer, investigating photosynthesis in grain legumes. They are currently assessing CGIAR scientists to involve in his research program.

Two of the Legume Scholars were able to attend the 2016 Pan-African Grain Legume and World Cowpea Conference in Zambia this past year. We will be ensuring that the Legume Scholars have more opportunities to present their research and network with the international community of researchers in the next few years, as they advance in their degree programs. A new Associate Award is expected to be established in FY 2017 for this program to ensure that the full PhD training period will be covered with adequate funding.

Training

Short-Term Training Programs

Fourteen short-term training programs were conducted through LIL projects. The project researchers, United States 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 help enhance grain legume value chains. A total of 1,516 men and 1,678 women participated in these short-term training activities, mostly held in Central America and Sub-Saharan Africa.

In the table below, the 14 short-term training programs are documented, involving 3,194 trainees, including research staff, farmers, private sector stakeholders, and others. The programs were national and regional, covering a range of topics, including research technology and field research implementation, innovation platforms and farmer learning, and theory and use of integrated pest management. A total of 52 percent of the trainees were women.

Country of Training	Brief Purpose of Training	Who was Trained	Male Trainees	Female Trainees	Total Trainees
	National Programs				
Zambia	Training on the use of PhotoSynQ for field data collection from field experiments	University of Zambia students and staff at the Zambian Agric. Research Institute (ZARI)	6	3	9
Ghana	Training on the use of animated videos of SAWBO with agricultural technologies (several training sessions in different parts of Ghana)	Staff of the NGO Center for Learning and Community Development (CLCD)	300	300	600
Burkina Faso	Farmer use of Integrated Pest Management	INERA staff and selected local farmers	68	52	120
Niger	Farmer use of Integrated Pest Management	INRAN staff and selected local farmers	50	115	165
Uganda	Innovation Platform based training on soil classification, postharvest storage, safe use of pesticides, seed selection and processing, marketing, conducting bean research trials	Innovation Platform members from local farmer organizations	863	1088	1951
Mozambique	Bean production technology and post-harvest handling methods	Staff of IIAM and farmers	57	21	78
Mozambique	Create awareness about soil fertility problems and build broader partnership among agricultural practitioners	Staff of IIAM, students at CEID in Gurúé	47	23	70
Mozambique	Building skills in soil data gathering and recordkeeping for soils description and classification	Staff of IIAM	6	3	9
Malawi	Research ethics, technical writing and publication process in agricultural economics and agribusiness	Students and staff of Lilongwe University of Ag and Natural resources (LUANAR)	44	16	60
Malawi	Development and management of supply chain relationships	Agribusiness industry stakeholders	21	22	43
Malawi	Training on field research guidelines, anthropometric data collection, biological sample collection and community engagement for biological research	Field staff from Ministry of Health and staff from University of Malawi College of Medicine	15	10	25
Malawi	Food safety aspects related to legumes and other Malawian crops	University of Malawi College of Medicine staff	22	19	41
	Regional Programs				
USA (NDSU)	Training on modern plant breeding and bean production systems in the US	Researchers from ICTA (Guatemala) and Zamorano (Honduras)	3	3	6
USA (Univ. Puerto Rico)	Training on research techniques related abiotic stress	Researchers from Central America (Costa Rica, El Salvador, Nicaragua, Honduras, Guatemala) and the Caribbean (Haiti)	14	3	17
Total			**1516**	**1678**	**3194**

Table 1. Feed the Future Legume Innovation Lab Short-Term Training Programs during FY2016

Long-Term Degree Training

Long-term degree training is a fundamental part of the collaborative research sponsored through the Feed the Future Legume Innovation Lab. Degree candidates are research partners, becoming professionals as they learn the tools of the trade and advance their degrees. The relationships that they form during training provide the base for future research collaborations. Research assistantships result in professional relationships and engagement in LIL research, with responsibilities and intellectual ownership of the research conducted.

In FY 2016, Feed the Future Legume Innovation Lab projects fully or partially funded 55 female and 75 male students, for a total of 130 students in university degree programs, including five Legume Scholars. Of those students in this degree training, 80 were studying at African universities, 28 at Latin American Universities, and 22 in U.S. universities.

Of the 130 students, 98 are currently in degree programs and 32 were granted their degrees during FY 2016. All but a few of the recent graduates have returned or were trained in their home countries; a few remained to pursue advanced degrees. We do not have full tracking on students who completed their programs this year. Among the students, there are 98 of African nationalities, 33 from Caribbean and Central America, and four from the United States. Most students are only partially funded under LIL, with research costs or other aspects related to their training program, only. Such limited coverage enables the leveraging of training resources at other universities.

Institutional Capacity Strenthening

The Feed the Future Legume Innovation Lab sets aside funding each year for host country researchers to propose institutional capacity strengthening activities. This funding is designed to meet critical basic needs of the institutions and our research partners and is highly valued to address an urgent demand. The funds are allocated on a competitive basis, with the TMAC providing their recommendations to the Management Office. In FY 2016, the TMAC approved funding for $159,138 of capacity strengthening projects; ten institutions in 10 countries received this funding. Many of the sponsored projects will be implemented during FY 2017. Many projects combined training activities with rehabilitation of facilities and the purchase of new equipment and supplies.

2016 Joint Pan-African Grain Legume and World Cowpea Conference

The Legume Innovation Lab and its CGIAR partners designed the Pan-African Grain Legume and World Cowpea Conference to ensure that national researchers could present their research and initiate new professional linkages throughout the region and with international researchers. Scientists presented their research and attended sessions on innovative methodological approaches and new technologies, contributing to a healthy debate on priorities for research investment. Participants in the conference were overwhelmingly favorable with regard to the substance of the conference and indicated that they would be following up on the contacts with new research collaborations. This international platform for their research increases LIL's institutional profile in the region.

This conference was also an excellent opportunity for graduate students and young researchers to meet one another and the wider community of researchers and donors. For these young scientists, the Feed the Future Legume Innovation Lab provided $100,000 in travel grants. The Bill & Melinda Gates Foundation, Kirkhouse Trust, and the McKnight Foundation provided additional travel or registrations grants, such that 53 young scientists were directly sponsored to attend. Additional young scientists were funded by their own institutions or through the CGIAR funding. For them, the opportunity to present their work in a professional setting, to discuss new and path-breaking research methods and results, to meet internationally renowned legume scientists, and to begin forming and growing their professional networks was all viewed as very important.

Beneficiary Host Country Institution	Approved Activity
ICTA, Guatemala	Rehabilitate parts of drip irrigation system and recondition the seed storage/ germplasm bank
University of Zambia, Zambia	Improve irrigation capacity at the University of Zambia research farm
Zambia Agriculture Research Institute - ZARI	Upgrading of seed storage facility
Escuela Agricola Panamericana Zamorano, Honduras	Purchase of a replacement autoclave, essential piece of equipment for the bean research program to screen for pathogen resistance
INERA, Burkina Faso	Enhancing capacity of seed laboratory to test seed, calibrate breeder seed as well as large-scale seed quality testing prior to distribution
ISRA, Senegal	Rehabilitation of a screenhouse to develop capacities in phenotyping
CSIR-SARI, Ghana	Rehabilitation of laboratory for culturing and infecting flower thrips at the Manga Station
INERA, Burkina Faso	reconditioning of cowpea insect pest-rearing rooms
INRAN, Niger	Lab enhancements to facilitate parasitoid multiplication
IIAM, Mozambique, and NARL, Uganda	Identification of options for mobile phone applications (apps) to enhance communication between researchers, extension, and farmers, as well as adapting selected technical packages and materials for sharing via apps

Table 2. Legume Innovation Lab Institutional Capacity Strengthening Projects in FY2016

On the back cover:

1 Sostino Mocumbe, IIAM and a LIL collaborator in Mozambique, explains the steps to produce quality bean seed to an audience of local farmers, using an illustrated poster. (SO2.1).

2 A healthy field of the improved bean variety Zenith, a high yielding black bean variety developed by the MSU Bean Cooperative breeding program (SO1.A3).

3 Cowpeas at a market in Benin are indicative of the various types sold in West Africa. Smallholder farmers consume and market cowpeas, so it is a valuable crop for both family food security and household income.

4 Women farmers and their children watch and learn from an instructional video in Mozambique. (SO2.1)

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