TEN-YEAR LEGACY REPORT

of the

Dry Grain Pulses CRSP (2007-2012)

and the

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (2013-2017)

FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative
USAID
FROM THE AMERICAN PEOPLE
Legume Innovation Lab

Ten-Year Legacy Report

2007–2017

Dry Grain Pulses CRSP (2007-2012)
and the
Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (2013-2017)

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Director's Message

As the Dry Grain Pulse Collaborative Research Support Program (DGP CRSP, 2007-2012) and Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (LIL, 2013-2017) come to an end, I am prompted to reflect on the program's legacy. What was its impact? What will endure?

The answer to this legacy question is complex since the program built upon a foundation of collaborative institutional relationships and research achievements on beans and cowpeas established through several Bean/Cowpea CRSP program phases extending from 1980 to 2006. At the inception of the DGP CRSP in 2007, the program was already an internationally-recognized "institution" with a collaborative research mission focusing on common bean and cowpea (vitally important food security crops in Sub-Saharan Africa and Latin America), and access to a multidisciplinary community of leading U.S. and developing country scientists and institutions who were working on grain legumes. It also had tested operational guidelines and administrative experience that would prove to serve it well going forward.

The challenge though faced by the Management Office (MO) at Michigan State University, the Management Entity, was to define an innovative new technical research vision for the Dry Grain Pulses CRSP (subsequently rebranded as the Legume Innovation Lab) and to constitute a coherent multifaceted portfolio of competitively awarded research and institutional capacity strengthening projects. The proposed technical vision sought to address the "wicked challenges" facing smallholder bean and cowpea farmers and the socio-economic and agro-ecological realities of rural communities in developing countries in 2007. The technical vision was later modified in 2011 to be aligned with the U.S. government's Feed the Future Research Strategy.

The MO also recognized in 2007 that it was afforded a unique opportunity to implement new approaches to strengthening host country institutional research capacity, to recruit a younger generation of Principal Investigators who could bring to bear modern science to achieving the program's research objectives and to create an innovative external technical and administrative advisory group (e.g., TMAC). Moreover, the MO desired to take the next step in establishing the program as an international leader in bean and cowpea research. To achieve this goal, the MO engaged USDA/ARS bean scientists, private industry groups (US Dry Bean Council, American Pulse Association, state bean commissions) and CGIAR grain legume research programs (IITA, CIAT, ICRISAT) to ensure that the DGP CRSP/LIL was responsive to industry trends and emerging research areas (e.g., child nutrition, climate resilience, edaphic constraints, decision support aids). Through strengthened ties with these organizations, the DGP CRSP and LIL were able to better complement and coordinate its portfolio of research projects with other international grain legume research efforts.

This report prepared by the MO seeks to document the major contributions and achievements by the DGP CRSP and LIL over the past ten years that we believe give testament to the program's success and will be an integral part of its legacy. It is hoped that the readership of this report will find the narratives on the research strategies, the cross-cutting themes, the exciting new technologies, the impacts achieved, and the novel administrative approaches implemented to be interesting and worthy of closer examination.

To be clear, however, this report was not intended to be a detailed scientific publication targeting a research audience. The intended audience for this report was envisioned to be much broader, including policy makers in government, agriculture development professionals, educators, institutional research administrators, and certainly stakeholders of grain legume value chains in FTF countries and the U.S. Our hope was that future leaders of USAID sponsored Innovation Labs might also discover learned lessons, ideas for scaling up and possibly strategy nuggets that might enable them to better design and implement robust research and institutional strengthening programs in the future.

This Legacy Report along with DGP CRSP and LIL workplans, technical reports, impact briefs, technical highlights reports, bibliographies of publications, and external evaluation reports will continue to be made available by Michigan State University to the general public. Electronic documents can be accessed and downloaded from the Legume Innovation Lab web page at http://www.canr.msu.edu/legumelab/ .

Many individuals are responsible for the scientific achievements highlighted within this Legacy Report. As Director, I want to take this opportunity to express my sincerest gratitude to the more than 60 scientists affiliated with 15 U.S universities and the USDA-ARS, plus more than 150 scientists from partnering institutions (NAROs, universities, NGOs) in 21 countries in Sub-Saharan Africa and Latin America and the Caribbean who contributed in significant ways to the research and human resource development achievements of the DGP CRSP and LIL. The participating host country institutions represented seven West African countries (Benin, Burkina Faso, Ghana, Mali, Niger, Nigeria and Senegal), four Central African countries (Kenya, Rwanda, Tanzania and Uganda), five Southern African counties (Angola, Malawi, Mozambique, South Africa and Zambia) and five Latin American and Caribbean countries (Ecuador, Guatemala, Haiti, Honduras, and Nicaragua). The commitment to scientific excellence and to applying their knowledge and research craft for the benefit of smallholder grain legume farmers and consumers in Africa and Latin America is to be lauded. It was a privilege for me as director to support and be an advocate for these distinguished grain legume scientists who were the heart and soul of the program and deserve credit for the program's successes.

A brief description of each subcontracted project in the DGP CRSP and LIL, the identity of the Principal Investigators and their respective institutions, and of the beneficiary countries can be found in Appendixes 1 and 2. The scholarly publications resulting from project research are listed in Appendixes 3 and 4.

I also want to thank the highly competent and dedicated administrative staff at MSU that I have been fortunate to work with over the past ten years. During this period, Drs. Mywish Maredia, Johannes Brink and Cynthia Donovan served as Deputy Directors providing valued expertise in impact assessment, biotechnology, socio-economics and gender which clearly strengthened the program. These Deputies challenged and helped sharpen the program's technical vision and research strategy, assumed responsibility for critical areas within the program, and provided a constant source of encouragement as the Management Office dealt with the daily adventures of international research program administration.

The DGP CRSP and LIL was also blessed with two outstanding international contractual and financial management officers, Ben Hassankhani (deceased) and Angelica Santos. The knowledge required, the ability to multi-task and administer a complex array of international subcontracts, the attention to detail to ensure compliance with standard provisions of USAID contracts, the integrity that instills trust and the ability to maintain a smile during challenging times made these two individuals special and a valued asset to the program.

Many other Management Office staff at MSU, too numerous to mention, also provided meritorious service to the DGP CRSP and LIL over the years. The mantra of the MO was that "each day was an adventure", "nothing is as simple as it first seems", and "one needs to always remember whom we serve, the smallholder resource poor grain legume farmers and the participant scientists and their respective institutions in the program." Their passion and commitment to team work and the goals of the program made coming to work each day a joy.

On behalf of Michigan State University, I want to thank the Office of Agriculture Research and Policy, Bureau for Food Security, USAID, for its willingness to invest in the proposed Technical Applications for the DGP CRSP and LIL, and confidence in MSU's capacity to administer the program. I believe that this Legacy Report gives testament to the program's significant contributions to advancing Feed the Future development goals and to the undeniable return on the investment from the research and capacity strengthening activities. Even though impacts have already be documented, the knowledge and technologies generated will continue to reap dividends for years to come in terms of increased grain legume productivity, resiliency of smallholder farms to climatic, agro-ecological and socio-economic perturbations, improved livelihoods of stakeholders of grain legume value chains, and greater food and nutritional security for all.

Please join me in celebrating the "legacy" of the Dry Grain Pulses CRSP and the Feed the Future Legume Innovation Lab.

Dr. Irvin Widders

Irvin E. Widders

Director
Feed the Future
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Abbreviations and Acronyms

ADP .... Andean Diversity Panel

ALS .... Angular Leaf Spot

ANT .... Anthracnose

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

APA .... American Pulse Association

ARS .... Agricultural Research Service (USDA)

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

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

BIC .... Bean Improvement Cooperative

BIFAD .... Board of International Food and Agriculture Development

BGYMV ...... Bean Golden Yellow Mosaic Virus

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

BNF .... Biological Nitrogen Fixation

Bt .... *Bacillus thuringiensis*

BTD .... Bean Technology Dissemination

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

CBB .... Common Bacterial Blight

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

CERAAS ..... Centre d'Etudes Régional pour l'Amélioration de l'Adaptation à la sècheresse (Senegal)

CG .... CGIAR

CGIAR .... Consultative Group on International Agricultural Research

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

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

CRP .... Consortium Research Program

CRSP .... Collaborative Research Support Program

CSB .... Community Seed Bank

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

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

DDL .... Development Data Library

DEC .... Development Experience Clearinghouse

DEPI......... Dynamic Environmental Phenotyping Imager

DICTA .... Dirección de Ciencia y Tecnología Agropecuaria (Honduras)

DGP .... Dry Grain Pulses CRSP

DOI.......... Digital Object Identifier

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

EED .... Environmental Enteric Dysfunction

EET.......... USAID commissioned External Evaluation Team

FAO .... Food and Agriculture Organization

FARA........ Forum for Agricultural Research in Africa

FTF.......... Feed the Future

FUNDIT ...... Fundación para la Innovación Tecnológica, Agropecuaria y Forestal (Guatemala)

GBS .... Genotyping by Sequencing

GDA......... Global Development Alliance

GPC .... Global Pulse Confederation (previously known as CICILS)

GWAS .... Genome-Wide Association Study

HC .... Host Country

HYPERS ..... Hyperspectral Imaging

IAR...........Institute of Agricultural Research, Sumaru (Nigeria)

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)

IER .... Institut d'Economie Rurale, Mali

IFPRI .... International Food Policy Research Institute

IIAA .... Instituto de Investigação Agronómica- Angola (Angola)

IIAM......... Instituto de Investigação Agrária de Moçambique (Mozambique)

IICA .... Inter-American Institute for Cooperation on Agriculture

IITA.......... International Institute of Tropical Agriculture

INERA .... Institut de l'Environnement et de Recherches Agricoles (Burkina Faso)

Indel......... Insertion/deletion markers

INIAP........ Instituto Nacional de Investigaciones Agropecuarias (Ecuador)

INRAB....... Institut National des Recherches Agricoles du Bénin (Benin)

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

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

IP . . . . Innovation Platform

IPM. . . . . Integrated Pest Management

IPM-omics. . . . Use of genomic tools in Integrated Pest Management

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

ISU . . . . Iowa State University

IV . . . . Improved Variety

IYP . . . . International Year of Pulses

KARI . . . . Kenyan Agriculture Research Institute

KSU . . . . Kansas State University

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

LSP. . . . . Legume Scholars Program

LUANAR . . . . . Lilongwe University of Agriculture and Natural Resources (Malawi)

MAGIC. . . . . . . Multiparent Advanced Generation Inter-Cross

MAS . . . . Marker-Assisted Selection

MaviMNPV . . . Maruca vitrata (F.) multi-nucleopolyhedrovirus

ME . . . . Management Entity of the Legume Innovation Lab (Michigan State University)

MGP . . . . Mwen Gen Pwa Bean Seed Relief Project in Haiti

MO . . . . Management Office of the Dry Grain Pulses CRSP and Legume Innovation Lab

MSU . . . . Michigan State University

MSPAS. . . . . . . Ministerio de Salud Pública y Asistencia Social (Guatemala)

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

NARL. . . . . .National Agriculture Research Laboratory (Uganda)

NARO . . . . National Agriculture Research Organization

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

NDSU. . . . . North Dakota State University

NGOs. . . . . Nongovernmental Organizations

NSS . . . . .National Seed Service, Ministry of Agriculture (Haiti)

PABRA . . . . . . Pan-African Bean Research Alliance

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

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

PI . . . . Principal Investigator

PR. . . . . Puerto Rico

PVCI-Z. . . . . . . Pulse Value Chain Initiative-Zambia

QDS . . . . Quality Declared Seed

QTL . . . . Quantitative Trait Loci

RAB . . . . Rwanda Agriculture Board (Rwanda)

RALS . . . . Rural Agriculture Livelihoods Survey

RIL . . . . Recombinant Inbred Lines

RMC . . . . Research Management Committee

RFP . . . . Request for Proposals

SSA . . . . Sub-Saharan Africa

SABREN . . . . . Southern African Bean Research Network

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

SCAR . . . . Sequence Characterized Amplified Region

SNF . . . . Symbiotic Nitrogen Fixation

SNP . . . . Single Nucleotide Polymorphism

SO . . . . Strategic Objective

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

TAMU. . . . . Texas A & M University

TARS . . . . Tropical Agriculture Research Station, USDA/ARS, Mayaguez, Puerto Rico

TDP . . . . Tepary Diversity Panel

TMAC. . . . . Technical Management Advisory Committee

UCD . . . . University of California-Davis

UCR . . . . University of California- Riverside

UDS . . . . University Development Studies (Tamale, Ghana)

UGA . . . . University of Georgia

UJES . . . . Universidade José Eduardo dos Santos (Angola)

UNZA. . . . . University of Zambia

UNL . . . . University of Nebraska- Lincoln

UPR . . . . University of Puerto Rico

URL . . . . Uniform Resource Locator

US. . . . . United States of America

USDA. . . . . United States Department of Agriculture

USDBC . . . . . . United States Dry Bean Council

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

WA. . . . . State of Washington

WHO . . . . World Health Organization

WTP. . . . . Willingness to Pay

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

Executive Summary of Legacy Report

The Legacy Report of the Dry Grain Pulses CRSP (2007-2012) and Feed the Future Legume Innovation Lab (2013-2017) program summarizes the innovative administrative leadership, technical research, training, and institutional capacity strengthening achievements that give evidence of the program's performance and contributions to improving the livelihoods of stakeholders of grain legume value chains in Feed the Future priority countries and regions. The salient achievements are described in this Legacy Report through a series of articles in seven important areas.

A. **Technical Vision:** Research themes and strategic objectives were formulated that responded to USAID's Initiative to End Hunger in Africa and the Feed the Future Research Strategy (2011). A portfolio of competitively awarded multidisciplinary collaborative research and institutional capacity strengthening projects focusing on common bean and cowpea was constituted and implemented in 21 countries in Sub-Saharan Africa, Latin America and the Caribbean. (A.1 and 2; Appendix 1 and 2)

B. **Improving Grain Legume Productivity:** Meaningful advances in increasing bean and cowpea productivity on smallholder farms were achieved through the development and release of 93 high yielding varieties with resistances to economically important diseases and insect pests, adaptations to drought, high temperature and low fertility, and preferred grain quality traits. The development of sustainable bio-controls for cowpea insect pests will close the yield gap in cowpea systems. (B.1 - 6)

C. **Improving Smallholder Farmer Integrated Crop Management Decision Making and Livelihoods:** Innovative approaches (innovation platforms), tools (decision support aids, SAWBO, soil maps), and models (community based seed multiplication) will enable marginalized smallholder bean and cowpea farmers to have access to technologies and make better integrated crop management decisions. (C.1 – 5)

D. **Improving Human Nutrition and Health:** Landmark findings on the roles of cowpea and bean in reducing growth faltering (stunting) and gut inflammation in young children, respectively, plus the identification of health promoting bioactive compounds in cowpea will give rise to food-based strategies for improving child growth and nutrition in nutritionally compromised regions of the world. (D.1 and 2)

E. **Strengthening Human and Institutional Capacity:** A new generation of grain legume scientists, with cutting edge research skills and a mindset for innovation, who appreciate the value of multidisciplinary collaboration and are networked, will be returning to their home countries and research institutions to be problem solvers, catalysts of sustainable change, and advocates for strengthened grain legume value chains. (E.1-3)

F. **Evidence of Achievement and Impact:** Demonstrated impacts to the grain legume sectors in both Feed the Future countries and the U.S. and scholarly research publications give evidence of the incredible performance by program PIs. (F.1-4; Appendix 3 and 4)

G. **Administrative Leadership by Michigan State University:** Effective technical and administrative leadership by the Management Office at Michigan State University has contributed to bringing international distinction to the DGP CRSP and LIL. It is now recognized as a premier multidisciplinary community of fundamental to applied scientists collaborating in grain legume research and committed to innovation and transformation of grain legume value chains. (G.1-4)

SECTION A
Technical Vision

Strategic Vision for the Dry Grain Pulses Collaborative Research Support Program and the Feed the Future Innovation Lab for Collaborative Research on Grain Legumes {A1}

The global mission of the Dry Grain Pulses Collaborative Research Support Program (DGP CRSP) and the Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (Legume Innovation Lab, LIL) was "to alleviate rural poverty, achieve food and nutritional security, and sustainably improve the livelihoods and resilience of stakeholders of grain legume value chains in Feed the Future focus countries in Africa and Latin America and in the United States."

The DGP CRSP (2007-2012) sought to achieve its mission through a portfolio of innovative, multidisciplinary and integrated research, institutional capacity strengthening and outreach activities that focused on common bean, cowpea, and related dry grain pulses and addressed specific technical objectives under four themes. These themes were a response to USAID's Initiative to End Hunger in Africa (IEHA).

a. To reduce bean and cowpea production costs and risks for enhanced profitability and competitiveness

b. To increase the utilization of bean and cowpea grain, food products and ingredients so as to expand market opportunities and improve community health and nutrition

c. To improve the performance and sustainability of bean and cowpea value-chains, especially for the benefit of women, and

d. To increase the capacity, effectiveness and sustainability of agriculture research institutions which serve the bean and cowpea sectors and developing countries.

> Global mission — To alleviate rural poverty, achieve food and nutritional security, and sustainably improve the livelihoods and resilience of stakeholders of grain legume value chains in Feed the Future focus countries in Africa and Latin America and in the United States.

In 2011, USAID formulated a Feed the Future Research Strategy to better focus CRSP research to underpin and contribute to the agricultural development priorities of the new Presidential Initiative "Feed the Future". For the final two years of the DGP CRSP and the following four and a half year LIL phase, the program's research agenda was aligned with Feed the Future strategic research priorities.

The Strategic Objectives (SOs) that defined the Legume Innovation Lab's research and institutional capacity strengthening portfolio for the performance period 2013-2017 were:

a. SO1. *Advancing the Productivity Frontier*: To substantively and sustainably increase grain legume productivity by improving adaptation to diverse agro-ecologies and reducing smallholder farmer vulnerability to climate change, with special consideration for the livelihoods of women.

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

b. SO2. *Transforming Grain Legume Systems and Value Chains*: To transform grain legume-based systems through improved smallholder production management decision making and more effectual governance management of grain legume value chains by stakeholders

c. SO3. *Enhancing Nutrition*: To improve the nutritional quality of diets and to enhance the nutritional and health status of the poor, especially women and young children, through the consumption of edible grain legume-based foods

d. SO4. *Improving Outcomes of Research and Capacity Building*: To improve outcomes of legume research and capacity building projects and to assess impacts to improve future decisions

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

- Contributing directly to the FTF themes of: (1) Advancing the Productivity Frontier, (2) Transforming Key Production Systems, and (3) Enhancing Nutrition and Food Safety;
- Assuming a leadership role within the international grain legume research community through engagement of leading scientists at U.S. universities and advanced HC research institutions, and through coordination with CGIAR legume scientists participating in the CG's Research Program on Grain Legumes;
- Focusing on priority FTF focus countries and cropping systems (the West African Sudano–Sahelian sorghum-cowpea systems, the Eastern and Southern African maize-based systems, and the maize–bean cropping system in Central America);
- Supporting Feed the Fuuture's whole-of-government approach through coordination with and engagement of USDA/ARS bean scientists;
- Enhancing the capacity of strategic national and international agricultural research institutions to address critical needs so as to be able to respond to future challenges of the grain legume sectors;
- Advancing gender equity through research, technology dissemination, and capacity building activities that directly benefit women;
- Achieving broad, quantifiable, sustainable impacts from outputs of LIL research as evidenced by widespread technology adoption and benefits to stakeholders of legume value chains—from smallholder farmers to consumers of grain legumes; and
- Supporting USAID country and regional mission FTF strategic value chains and agriculture sector development priorities.

The research and institutional capacity strengthening projects, that were competitively selected to achieve the focal themes of the DGP CRSP and the strategic objectives of the LIL, constitute a robust, comprehensive and synergistic program portfolio (See Appendix 1 and 2).

The program's vision was that individual project teams would interact and collectively work together toward achieving a common set of program goals and strategic objectives. In other words, the DGP CRSP and LIL program was envisioned, designed and implemented in a manner such so that the ultimate impact would be greater than the sum of the technological outputs or localized intermediate development outcomes. Lessons learned and technologies developed could be transferred and utilized in a cross-cutting manner to benefit research and development efforts involving other grain legume commodities and in other regions of the world.

This ten-year Legacy Report of research and institutional capacity strengthening achievements by the international community of scientists and institutions which partnered in the DGP CRSP and LIL program gives evidence of unparalleled performance in generating innovative technologies and new knowledge to improve the livelihoods of stakeholders of the grain legume value chains, in preparing a new generation of grain legume scientists, and in leadership by the Management Office to pursue and realize the global objectives of the Presidential Initiative Feed the Future.

Achieving Gender Priorities and Impacts in Grain Legumes {A2}

Women play a multiplicity of roles in grain legume value chains as farmers, seed producers, food processors, grain traders, research scientists, and extension educators. Under the Dry Grain Pulses CRSP (2007-2012) and the Feed the Future Legume Innovation Lab (2013-2017), the program directors and principal investigators (PIs) integrated gender equity as a priority cross-cutting theme across the research portfolio and in capacity strengthening initiatives. All project technical proposals and workplans were required to outline and implement a gender equity strategy. Breeders, soil scientists, entomologists, rural sociologists and economists focused on identifying the gender-differentiated demands and needs of farmers, consumers, traders, and processors. Recognizing the general lack of women in science, the DGP CRSP and LIL program gave priority to educational activities for young women scientists, including participation in scientific conferences and workshops, as well as long-term degree programs. The impact of these investments can best be appreciated by focusing first on ways in which women's issues were addressed across the grain legume sectors and then focusing on gender equity achievements through institutional capacity building initiatives.

Generating income generating opportunities for women entrepreneurs was important for the DGP CRSP and LIL program.

Women are vitally important in grain legumes from production to consumption. Women are recognized for their role in household food security, including meal selection and preparation. They often have primary responsibility for the production of grain legumes, especially because crops such as bean and cowpea are critical for the food and nutritional security of rural households. Women engage in many entrepreneurial activities with grain legumes, including the marketing of grain in local markets, the preparation and sale of processed grain legume-based foods, and the conservation, multiplication and sale of quality seed. Thus, an assessment of women's engagement was essential for the DGP CRSP and LIL program to identify technologies and opportunities to improve their livelihoods and to create a new generation of women to assume leadership roles in this sector.

On the production side, DGP CRSP and LIL researchers developed technologies that enhance women's productivity and abilities to sustainably manage a grain legume crop and provide nutrient-dense food for their families. Breeders released improved varieties of bean and cowpea (Section B.1) that are resistant to diseases, tolerant of drought and high temperatures and adapted to low fertility soils, especially important where women plant grain legume crops under marginal conditions for household consumption. Women generally have lower access to assets and income, limiting their capacity to purchase inputs, such as pesticides and fertilizers. Combining the varietal development with training to enhance women farmers' knowledge, motivation, and use of technologies and integrated crop management practices boosts productivity without significantly increasing costs. Also, biocontrol agents (Section B.5) will sustainably reduce the need and use of purchased synthetic pesticides, therefore ameliorating health and food safety risks especially for women. Diagnostic tools and decision support aids were tailored for use by women, and innovation platforms were implemented that engaged and served the needs of women farmers.

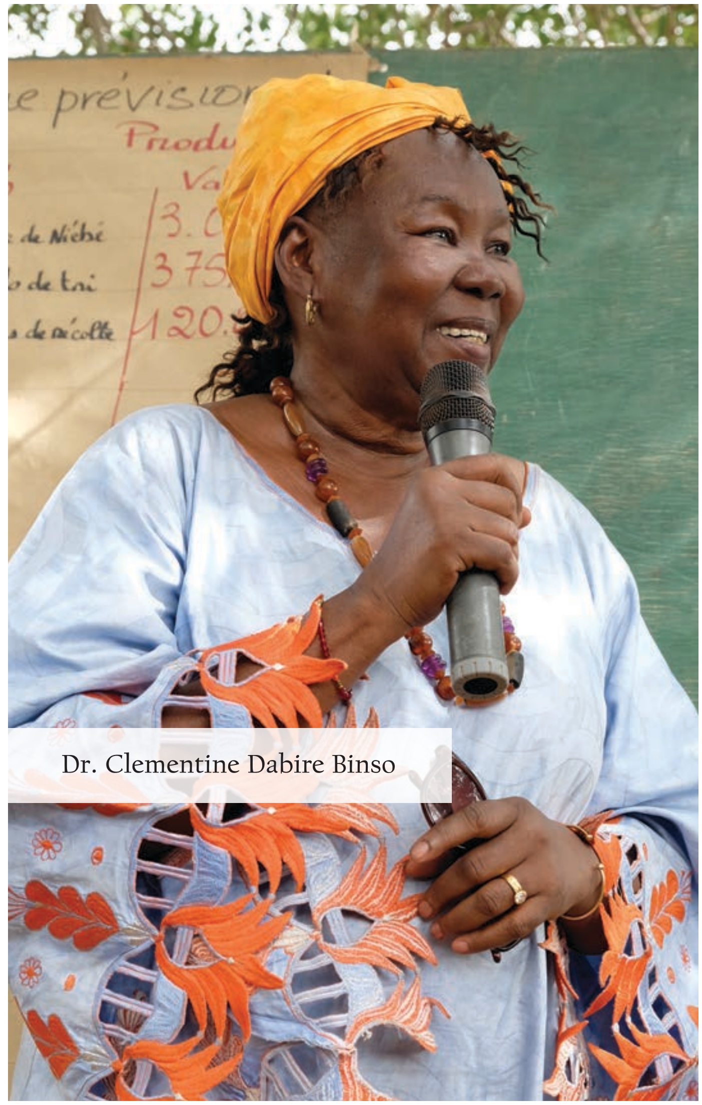
Storage of food supplies is also a responsibility of women, as they need to ensure adequate household food stocks for the year. LIL breeders developed bruchid (grain weevil) resistant varieties of common bean for Africa and Central America to respond to women's demand for beans and cowpeas for consumption during the off season and planting of next season's crop (Section B.3). The risk of bruchid damage forces farmers to sell their harvested beans and cowpeas early and then frequently to buy back grain later when prices are higher in order to feed their families. Women manage household consumption assets and will benefit from productivity enhancing and storage technologies generated by the DGP CRSP and LIL.

> DGP CRSP and LIL researchers developed technologies that enhance women's productivity and abilities to sustainably manage a grain legume crop and provide nutrient-dense food for their families.

Improved varieties of climbing beans are a technology that was developed to benefit Mayan women in the Western Highlands of Guatemala (Section B.6). Maize and beans are traditionally grown in an intercropped "milpa" system. ICTA-Guatemala breeders developed bolonillo climbing bean varieties that are more productive, cook more quickly, produce a thick broth preferred by local consumers and sell for a higher price in Guatemalan markets. 'ICTA Labor Ovalle' and 'ICTA Utilan' are two such varieties released with technical and financial support from LIL.

Nutrition is often considered the realm of women for they are responsible for the feeding of infant children and other family members. Feed the Future focuses on the first 1000 days as critical for growth and lifelong health and productivity. The provision of adequate nutrition to infants during the weaning stage is often a challenge. A Washington University in St Louis clinical study in Malawi (see Section D.1) evaluated the effects of bean or cowpea-based food supplements on child growth and gut health. These food supplements were developed by Lilongwe University of Agriculture and Natural Resources food scientists and students using locally available and affordable inputs. Researchers found that the roasted cowpea flour added to traditional porridge significantly lowered growth faltering (stunting), and that infants loved eating the porridge with the added cowpea or bean supplement.

In the MASFRIJOL-Guatemala associate award project, the multiplicity of roles of women became evident as educational interventions were designed. Mayan women are responsible both for agricultural production management decision making and the preparation of food for their families. It was therefore strategically important to engage women in all aspects of the project including in training activities on seed production, bean crop management, the preparation of nutritious bean-based foods, and in dietetics and nutrition.


Dr. Clementine Dabire Binso

In Sub-Saharan Africa, women are less likely to have received primary education and be literate. LIL training materials were developed for SAWBO (Section C.2) and the Innovation Platforms in Uganda and Mozambique (Section C.1) to reach low literacy learners. Communication materials based on verbal and pictorial (video) methods were found to be highly effective with women.

The cowpea IPM project (Section B.5), which developed sustainable biological controls for insect pests, collaborated with IITA scientists to conduct farmer field schools and establish innovation platforms that targeted women as well as male farmers. Women were found to be observant and ideal for monitoring pest pressure in fields and assisting in making safe and environmentally sustainable IPM decisions.

Income generating opportunities for women entrepreneurs were important for the DGP CRSP and LIL program. Opportunities were identified where women could play critical profit generating roles through the multiplication of quality bean and cowpea seed, the production of biopesticides for cowpea insect control, and the processing of value-added food products for sale in their community. For example, LIL INERA-Burkina Faso scientists provided technical assistance to women's groups on the production, handling and marketing of quality cowpea seed of improved varieties. These women's groups are now playing a strategic role in ensuring the "seed security" of Burkina Faso. The LIL cowpea IPM project (Section B.5) also provided training to women's groups on the production of biocontrols, including the rearing of parasitoids, the extraction of neem oils, and the culture of insect viruses for pod sucking insect control (*Maruca vitrata*).

The education of women was a priority for the DGP CRSP and LIL capacity building initiatives, both in formal degree and in short term training. During the ten years of this program (2007-2017), 42 percent of the trainees in degree programs, including Bachelors, Masters and PhD, were women.

The degree training programs offered through DGP CRSP and LIL provided flexible options and local training opportunities for women to participate and gain degrees. The Kansas State University Masters in Agribusiness Program (MAB) is a case in point. The two-year cohort-based program blended two week-long intensive campus-based courses each year with online training throughout the year. Four women students were able to complete degrees without spending extended time away from work and families. A significant amount of long-term degree training also took place at host country universities, enabling families to stay together during the training period. For example, nine women received degrees in agricultural economics from the University of Zambia, three from Lilongwe University of Agriculture and Natural Researchers (LUANAR) in Malawi and one from Sokoine University in Tanzania.

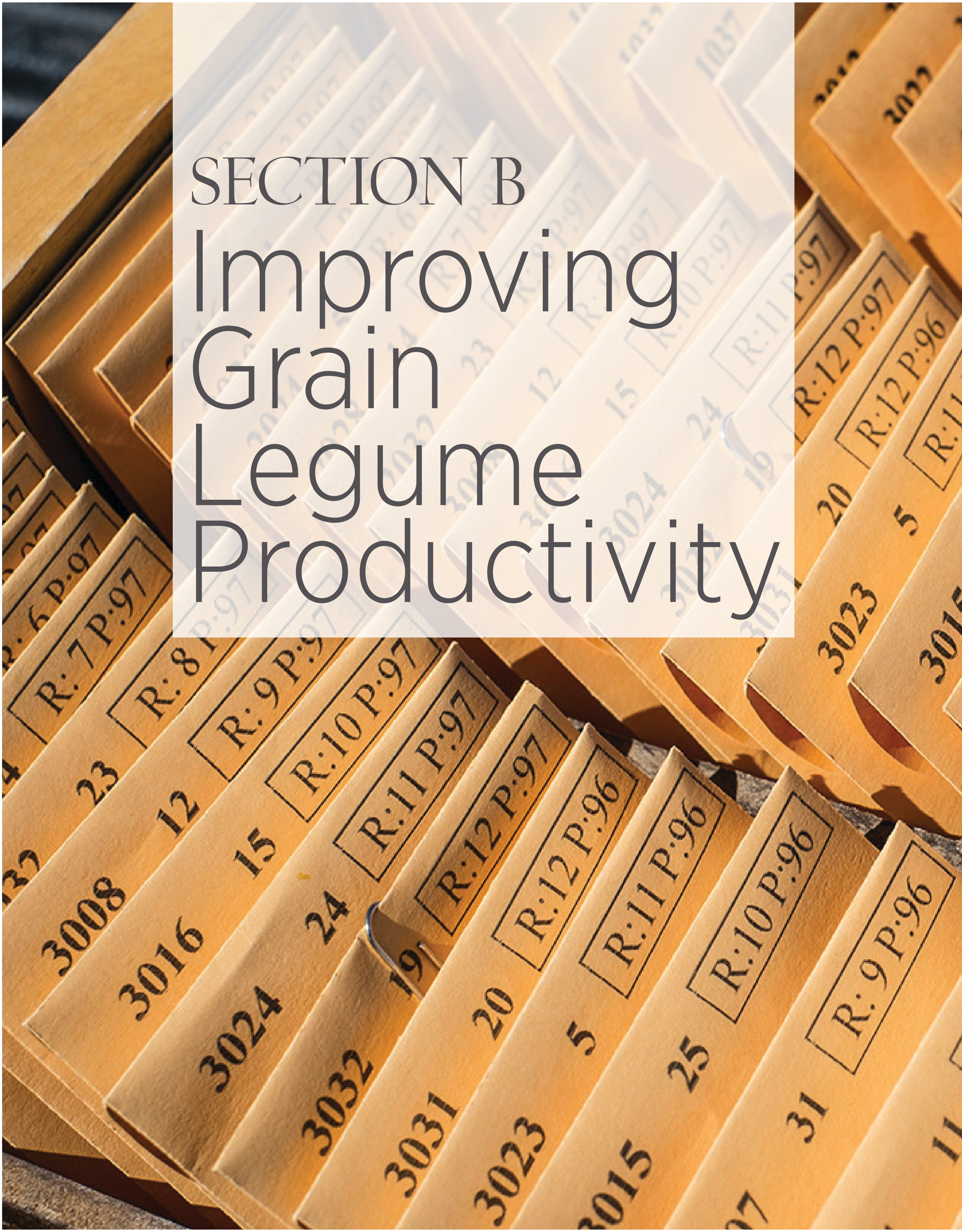
Short term educational activities for research and extension technicians, farmers, and other value chain stakeholders provided critical training on new technologies, improved crop management practices, and use of cutting-edge research tools and methods. Over 35,000 short term trainees were women, accounting for approximately 49 percent of all short term trainees during the DGP CRSP and LIL performance period.

Women in Agricultural Science Leading the Way for Other Women: Dr. Clementine Dabire Binso

A lead INERA scientist and PI embodied the true spirit of gender equity in the DGP CRSP and LIL program. Dr. Clementine Dabire, an entomologist and recipient of the distinguished TMAC Meritorious Achievement Award, was a pathbreaker in her home country of Burkina Faso. She is a woman scientist who led INERA's entomology research unit; playing a prominent role in the development of biological technologies to control insect pests in cowpea. She also went beyond the call of duty by reaching out to and providing technical assistance to women farmer associations, equipping them to be certified cowpea seed producers and suppliers of improved cowpea varieties in their communities.

Dr. Dabire encouraged women entrepreneurs to develop and market cowpea flour and other processed goods, generating income for them and demand for cowpea products in local markets. She also was an advocate for the training of young women scientists in degree programs. She brought many graduate students into her lab where they could be mentored and follow her example of scholarship, excellence and service to the community.

Thanks to her efforts and those of all the scientists in the DGP CRSP and LIL, there is a new generation of women engaged in grain legume research in Sub-Saharan Africa, Central America and the Caribbean.



SECTION B

Improving Grain Legume Productivity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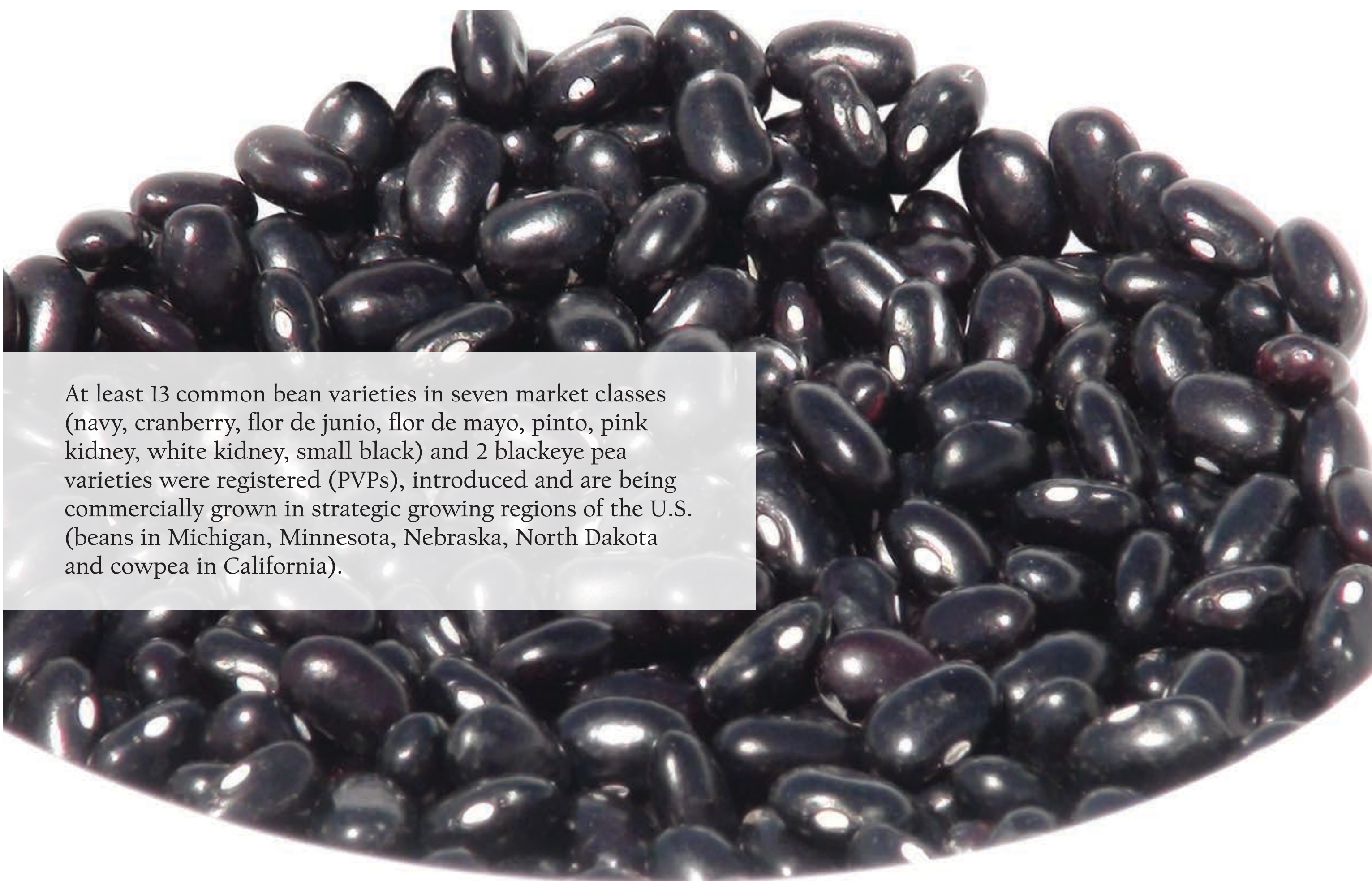
A Legacy of Improved Grain Legume Varieties to Benefit Smallholder Farmers {B1}

Over the past 10 years (2007-2017), the collaborative breeding model utilized by the Dry Grain Pulses Collaborative Research Support Program (DGP CRSP) and the Feed the Future Legume Innovation Lab (LIL) programs has produced an impressive legacy of high yielding bean and cowpea varieties of preferred grain types for the Feed the Future countries in Sub-Saharan Africa, and Central America and the Caribbean (Haiti).

The genius of the model is that national grain legume breeding programs in target Feed the Future focus countries take the leadership in making the crosses, selecting and releasing varieties that are high yielding, adapted to local agro-ecologies and have seed traits that are preferred by local farmers and consumers. Breeders of national agriculture research programs best understand local agricultural systems into which grain legumes fit, including the disease and insect pest problems plus the abiotic stresses such as drought, high temperatures and low soil fertility, that limit bean and cowpea yields on smallholder farms. Moreover, local breeders are best positioned to interact with both male and female farmers to gain insights into farmer preferences for grain and agronomic traits as well as for culinary and market traits important for household food and economic security.

The role of U.S. breeders in a collaborative breeding relationship is distinct from that of the national developing country breeders. Although U.S. public sector breeders largely focus on developing varieties for commercial U.S. production, they also have access to cutting edge genomic and molecular tools (markers) and genes for important traits that can be highly valuable to the national breeders. Through research collaborations, U.S. geneticists can make these available to African and Latin American breeders to improve the effectiveness and efficiency of their breeding efforts. For example, the use of marker assisted selection, QTL identification and Genome-wide Association Mapping can significantly



At least 13 common bean varieties in seven market classes (navy, cranberry, flor de junio, flor de mayo, pinto, pink kidney, white kidney, small black) and 2 blackeye pea varieties were registered (PVPs), introduced and are being commercially grown in strategic growing regions of the U.S. (beans in Michigan, Minnesota, Nebraska, North Dakota and cowpea in California).

BREEDING LINES DEVELOPED	MARKET CLASS AND UNIQUE TRAITS	BENEFICIARY COUNTRIES OR REGION	PARTNER INSTITUTIONS
Common Bean Lines			
AO-1012-29-3-3A	Bruchid, BCMN and BCMNV resistant Andean bean breeding line	Central America, Caribbean and Tanzania	UPR, Oregon Stare, UPR, USDA-ARS
ADP 0512, ADP 0009, ADP 0001, ADP 0468, ADP 0521, ADP 0098 and ADP 0522	Lines with short cooking time selected by farmers from Andean Diversity Panel (ADP)	Uganda	NaCCRI-Uganda, USDA-ARS, MSU
ADP 102, ADP 41, ADP47, SDP 61, ADP 617, ADP660, ADP 678	Lines with drought tolerance from Andean Diversity Panel (ADP)	Uganda	NaCCRI-Uganda, MSU
ALB 155, ALB 171, KWP 17 and KWP 9	Lines with resistance to Sclertium rolfsii root rot	Uganda	NaCCRI-Uganda, MSU
Cebo Cela, Elvhira	Lines with short cooking time (25 min.)	Uganda	USDA-ARS, NaCCRI-Uganda
NE2-14-8, NE17-14-29, NE14-09-78, VAX 3	Common bacterial blight resistance for both leaf and pods in Andean type	Uganda	NaCCRI-Uganda, UNL, MSU
Mexico 309, CNC, P1181996, Mexico 235, Ouro Negro, Redland Pioneer, Aurora	Rust resistant lines appropriate for Ugandan races	Uganda	NaCCRI- Uganda, U. Nebraska-L
PRO401-259	Web blight ,BGYMV and BCMV resistant bean breeding line	Caribbean, Central America	UPR, USDA-ARS
PR0650-31	Line which combines resistance genes for BGYMV, BCMV, CBB and web blight	Caribbean, Central America	UPR, USDA-ARS
PR0737-1 and PR0633-10	Red mottled bean breeding line with resistance to BGYMV, BCMV and BCMNV	Caribbean	UPR, NSS, USDA-ARS
PRO806-81	Small white, tropical adaptation, resistance for BGYMV, BCMNV, BCMV and rust. Combines Andean rust gene UR-4 and Mesoamerican rust resistance genes Ur-5 and Ur-11	Central America, Caribbean	UPR, USDA-ARS, MoA-Haiti
SB-DT1	Small black seeded line with drought and high temperature tolerance and resistance to BCMV and root rots	Central America, Caribbean	USDA-ARS, UPR
SCR 26, SEN 98, SCN 11 and SCN 1	Small black, promising lines for drought & high temperature tolerance, resistant to BCMV and root rots	Uganda	MSU, UNL, NaCCRI-Uganda
SCR 48, SCN 9, SCN 6	BCMV resistance in Andean bean market class	Uganda	NaCCRI-Uganda, MSU
TARS-LFR1	Small red line with root rot resistance, tolerance to low fertility & leaf hopper, resistance to web blight, CBB, BCMV	Cenral America, Caribbean	USDA-ARS, UPR
TARS-MST1	small black seeded line with drought and high temperature tolerance and resistance to BCMV, CBB and root rots	Central America, Caribbean	USDA-ARS, UPR
Tepary Dirversity Panel	Tepary lines with resistance to BCMV, BCMNV and/or BGYMV identified	Central America, Caribbean	USDA/ARS, UPR
Cowpea Breeding Lines			
SARC-1-57-2	cowpea aphid resistance	Ghana	SARI-Ghana, UCR
IT97K-556-6	cowpea aphid resistance	Ghana	SARI-Ghana, UCR
SANZI, TVx3236 and TVu1509	cowpea flower thrips resistance	Burkina Faso	INERA-Burkina Faso, UCR
SANZIx58-77, ISRA-3178, ISRA-3217	cowpea flower thrips resistance	Senegal	ISRA-Senegal, UCR
IT86D-716 x Nafi segregating population	pod-sucking bug resistance	Burkina Faso	INERA-Burkina Faso, UCR

TABLE 1: Breeding lines with important traits developed through DGP CRSP and LIL collaborative projects.

accelerate progress in the breeding of beans and cowpeas with the desired combination of traits in an appropriate market class desired for a specific country context.

Table 1 identifies numerous bean and cowpea breeding lines with unique traits that were identified through various screening protocols by Legume Innovation Lab projects and are now being used by breeders in Feed the Future countries. Noteworthy traits of importance identified in breeding lines include short cooking time, drought tolerance, resistances to diseases and insect pests that can completely wipe out a crop (e.g., web blight, root rots, leafhoppers), and greater adaptation to low soil fertility, plus combinations of traits in preferred market classes (e.g., small black bean, tepary bean, large seeded Andean beans consumed in Eastern Africa and the Caribbean).

An inventory of improved varieties that have been registered and formally released during the ten year performance period of the Dry Grain Pulses CRSP (2007-2012) and Legume Innovation Lab (2013-2017) (see Table 2, page 15) includes 60 common bean varieties, 2 tepary bean varieties, 1 dry lima bean variety, at least 18 new cowpea varieties, and 12 common bean varieties developed through a participatory plant breeding approach in Honduras. The output total of the program is therefore an impressive **93 new improved grain legume varieties introduced for commercial production.**

> 60 new common bean varieties, 2 tepary bean varieties, 1 dry lima bean variety, at least 18 new cowpea varieties, plus 12 varieties developed via participatory plant breeding were released during the DGP CRSP and LIL performance period (2007 – 2017). This represents an output total of 93 new improved grain legume varieties introduced for commercial production.

This remarkable achievement can the attributed to the combined collaborative common bean and cowpea breeding efforts of scientists at the Michigan State University (James Kelly, PI), University of Puerto Rico (James Beaver, PI), University of California-Riverside (Phil Roberts, PI), North Dakota State University (Juan Osorno, PI) and the USDA-ARS Co-PIs (Tim Porch, Phil Miklas and Karen Cichy) in partnership with genetic improvement programs at over 25 institutions in 13 Feed the Future countries in West, Central and South Eastern Africa, Central America and Haiti.

Of these new varietal introductions, a total of 43 common bean, tepary and lima bean varieties plus 12 varieties developed using a participatory plant breeding approach were released and are being grown commercially in Central American (Honduras, Guatemala, Nicaragua, Costa Rica, El Salvador and Panama) and Caribbean countries (Haiti, Dominican Republic) plus Mexico and Ecuador. In addition, ten new Andean type common bean varieties were released during this period in the Eastern and Southern African FTF countries of Uganda and Zambia.

The performance and potential impact of the cowpea breeding effort is equally impressive. A total of 16 new cowpea varieties were formally released in Senegal and Burkina Faso, two major cowpea producing countries in West Africa. The emphasis of this breeding effort has been on increasing cowpea grain size and whiteness which are important for urban markets in Nigeria, Ghana and Senegal, plus incorporating resistance genes to insect pests (thrips, aphids) and *Striga,* a parasitic weed. These projects also assumed responsibility for and supported the production of breeder and foundation seed to ensure that adequate seed stocks were available for multiplication so that smallholder farmers in the respective countries and regions could benefit from the improved genetic potential of these varieties.

Commercial bean and cowpea (blackeye pea) farmers in the U.S. (including Puerto Rico) also benefited from the Dry Grain Pulses CRSP and Legume Innovation Lab breeding program's outputs. At least 13 common bean varieties in seven market classes (navy, cranberry, flor de junio, flor de mayo, pinto, pink kidney, white kidney, small black) and 2 blackeye pea varieties were registered (PVPs) and introduced and are being commercially grown in strategic growing regions of the U.S. (beans in Michigan, Minnesota, Nebraska, North Dakota and cowpea in California). This provides compelling evidence of the dual benefits received by both developing country and U.S. agriculture from USAID's investment in grain legume breeding through this program.

Since many of the new common bean varietal releases in the U.S. are photoperiod insensitive enabling production at different latitudes and possess superior combinations of traits preferred by both farmers and consumers in developing countries, their potential to benefit smallholder bean farmers in Feed the Future countries is high. Zorro and Zenith, two small-seeded black bean varieties bred for Michigan (the #1 producer of black beans in the U.S.) have been widely adopted and are being commercially produced in the Petén region of Guatemala and areas in southern Mexico because of their robust drought tolerance and excellent culinary quality (a preferred thick broth when boiled). In a similar manner, bean varieties developed for the lowland tropical conditions in Puerto Rico are adapted and can be readily grown in other Caribbean, Central America and Eastern Africa countries.

Likewise, many of the common bean and cowpea varieties developed by breeding programs at partner developing country institutions under the DGP CRSP and LIL programs, such as EAP-Zamorano in Honduras and ISRA-Senegal, were positively evaluated, found to be well adapted, and thus have been officially released in neighboring countries in their respective regions. Examples of this are 'CENTA EAC', 'Lenca Precoz', 'INTA Centro Sur', and 'Matambu' varieties that were developed by the EAP-Zamorano bean breeding program led by Dr. Juan Carlos Rosas which have been released in El Salvador, Haiti, Nicaragua and Costa Rica, respectively.

DGP CRSP and LIL breeding projects are committed to promoting developing country ownership of improved varieties and the development of independent self-sustaining national breeding programs to support the grain legume industries within their respective countries.

Another noteworthy aspect of DGP CRSP and LIL breeding projects is their commitment to promoting developing country ownership of improved varieties and the development of independent self-sustaining national breeding programs to support the grain legume industries within their respective countries. In bean and cowpea projects, national breeding programs were responsible for making the crosses, engaging local farmers in the participatory selection of superior lines with the desired combinations of traits, the multi-location validation of field performance of elite lines, the registration of improved varieties in their respective countries, and the production of breeder and foundation seed. This commitment is evidenced by the breeding and release of 40 common bean varieties and 16 cowpea varieties by national programs, and 12 farmer participatory bred varieties locally released in Honduras. This represents nearly 70% of the common bean varietal introductions and 88% of the cowpea introductions over the past 10 years.

Tables 1 and 2 give credit to the primary institutions responsible for the breeding of the grain legume varieties developed with technical and financial support from USAID through the DGP CRSP and LIL programs. Other international breeding programs that have contributed to this breeding achievement include the Feed the Future USDA-ARS Andean bean breeding project, the CIAT bean program, member institutions of the Pan Africa Bean Research Alliance (coordinated by CIAT) and the IITA cowpea breeding program.

The great feature about USAID investments in bean and cowpea breeding programs through the DPG CRSP and LIL programs is that the legacy will continue. Because of the long-term 10 year investment in bean and cowpea breeding at NAROs and universities in Africa and Latin America, the breeding programs have matured and the “pipeline” of elite genetic lines with expanded combinations of genes for important traits has been filled. As these lines undergo their final generations of evaluation, selection and validation, new highly promising varieties should be forthcoming from these programs in future years.

Although this represents a great record of research achievements and outputs (93 newly released grain legume varieties from the DGP CRSP and LIL programs), the ultimate impact of this contribution to developing country agriculture and livelihoods of smallholder grain legume farmers will not be realized and appreciated for many years to come. As these improved varieties continue to be promoted, seed made accessible to farmers, and the varieties are adopted, the full impacts of the program on household food, nutritional and economic security will be achieved and become evident. This delay in return on investment is an inherent characteristic of public sector supported crop breeding programs.

The bottom line is that by all accounts, USAID Bureau for Food Security support for the DGP CRSP and the Feed the Future LIL programs over the past 10 years have been a most worthy investment that will bring multifaceted returns to both the focus countries and to the United States for many years into the future.

TABLE 2. Improved varieties of grain legumes developed and released with support through collaborative DGP CRSP and LIL projects during the period 2007 – 2017.

VARIETAL NAME	LINE OR PVP NO.	MARKET CLASS AND UNIQUE TRAITS	BENEFICIARY COUNTRY(S)	PARTNER INSTITUTIONS
Common Bean (Phaseolus vulgaris)				
Aifi Wuriti/INTA Negro	EAP 9712-13	small black, early maturity, BCMV & BGYMV resistant, low soil fertility tolerant	Honduras, Haiti and Nicaragua	Zamorano, UPR, MoA Haiti, INTA
Azabache/Sankara	XRAV-40-4	small black, BCMV, BGYMV & BCMNV resistance	Honduras, Haiti	UPR, Zamorano, UNL, IDIAF, DICTA
Beniquez		white, erect architecture, resistance to BGYMV, BCMV and BCMNV, rust, and heat tolerance	Puerto Rico, Caribbean	UPR, USDA/ARS
Cardenal/Chaparrastique	MER 2226-41	small red, heat tolerant, BCMV and BGYMV resistance	Honduras, El Salvador	Zamorano, DICTA, CENTA
DEORHO/Nahuat / Matagalpa	SRC2-18-1	small red, heat tolerant, BCMV and BGYMV resistance	Honduras, El Salvador and Nicaragua	Zamorano, DICTA, CENTA, INTA
	PRO806-80	small white, BCMV, BGYMV & BCMNV resistance, Ur-4, Ur-5 and Ur-11 rust resistance	Central America	UPR, USDA/ARS, MoA Haiti
	PRO806-81	small white, tropical adaptation, resistance for BGYMV, BCMNV, BCMV and rust. Combines Andean rust gene UR-4 and Mesoamerican rust resistance genes Ur-5 and Ur-11	Central America, Caribbean	UPR, USDA-ARS, MoA-Haiti
	AO-1012-29-3-3A	red kidney, bean weevil resistance, BCMV, BCMNV resistance, high protein	Central America, Eastern and Southern Africa	UPR, USDA/ARS, Oregon State, Sokoine Univ. Agriculture
CENTA CPC	PPB11-20MC	small red, BCMV & BGYMV resistance	El Salvador	Zamorano, CENTA, DICTA
CENTA EAC/Rojo Chortí	SIC-730-79	small red, heat tolerant, BCMV and BGYMV resistance	El Salvador, Honduras (2018 release)	Zamorano, CENTA, DICTA
ICTA Patriarca		small black, BCMV and BGYMV resistance	Guatemala (2018 release)	ICTA, Zamorano
ICTA Peten		small black, early maturity, mulitple virus resistance, high iron	Guatemala	ICTA, CIAT
ICTA Sayaxche	MEN 2207-17	small black, BCMV, BGYMV resistance, adapted to humid conditions	Guatemala	ICTA, Zamorano
ICTA ZAM	MHN 322-9	small black, heat tolerant, BCMV and BGYMV, common blight and web blight resistances	Guatemala	ICTA, Zamorano
ICTA Utatlan		black climbing bean, early maturity, adapted to highland milpa	Guatemala	ICTA, NDSU
ICTA Labor Ovalle		black bolonillo, climbing bean, adapted to highland milpa	Guatemala	ICTA, NDSU
INTA Centro Sur	IBC-301-304	small red, adapted to low fertility soils, BCMV & BGYMV resistance	Nicaragua	Zamorano, INTA
INTA Rojo Jinotega	RS 901-6	small red, drought tolerant, BGYMV & BCMV resistance	Nicaragua	Zamorano, INTA
INTA Seda 1	NIC 702	small red, BCMV & BGYMV resistance	Nicaragua	Zamorano, INTA
INTA Seda 2	NIC 704	small red, BCMV & BGYMV resistance	Nicaragua	Zamorano, INTA
INTA Tomabu	RS 813-43	small red, resistance to BCMV & BGYMV, tolerance to drought	Nicaragua	Zamorano, INTA
INIAP 485- Urcuqui	BCN 20-03-48	small black, resistance to BGYMV & BCMV, antracnose and rust, excellent canning quality	Ecuador	Zamorano, INIAP, MSU
Matambu	B2056	small black, resistance to BGYMV & BCMV	Costa Rica	Zamorano, INTA, ICTA
Lenca Precoz	MEN2201-64ML	small black, early maturity, BCMV, BGYMV & BCMNV resistance	Honduras, Haiti	Zamorano, DICTA, UPR, MoA Haiti
	PR1146-138	Andean yellow bean, BCMV and BGYMV resistance, leaf hopper resistance,	Haiti	UPR, USDA/ARS, MoA Haiti
	PR0633-10	red-mottled, BGYMV, BCMV, BCMNV,& CBB resistances	Haiti	UPR, USDA/ARS, MoA Haiti
	PRO737-1	red-mottled, BGYMV, BCMV, BCMNV & CBB resistance, leaf hopper resistance	Haiti (released)	UPR, USDA/ARS, MoA Haiti
Paraisito Mejorado 2 (Don Rey)	IBC 302-29	Seda-type small red, BGYMV & BCMV resistance, Paraisito landrace background, tolerant to low soil fertility & drought	Honduras	Zamorano, DICTA, UPR, PSU
	TARS-LFR1	small red, tolerance to low fertility, leaf hopper resistance, CBB, web blight and BCMV resistances	Central America, Caribbean	USDA/ARS, UPR
	TARS-MST1	small black, drought & high temp tolerance, CBB and BCMV resistance, root rot tolerance	Puerto Rico, Caribbean	USDA/ARS, UPR

VARIETAL NAME	LINE OR PVP NO.	MARKET CLASS AND UNIQUE TRAITS	BENEFICIARY COUNTRY(S)	PARTNER INSTITUTIONS
Rojo INIFAP	PRF 9653-16B-3	small red, heat tolerant, BCMV & BGYMV resistance	Mexico (released on 2005 in El Salvador)	Zamorano, CENTA, INIFAP
	SB-DT1	small black, drought & high temp tolerance, BCMV resistance, root rot tolerance	Puerto Rico, Caribbean	USDA/ARS, UPR
Surú	MEB 2232-29	small white, BCMV & BGYMV resistance	Costa Rica	Zamorano, INTA
Tayní	BCH 9901-56R	small red, BCMV & BGYMV resistance	Costa Rica	Zamorano, INTA
Tolupan Rojo	ALS-0532-6	small red, Angular Leaf Spot resistance, BCMV and BGYMV resistance	Honduras (2018 release)	Zamorano, DICTA
Tongibe	BC 9901-14	small red, BCMV & BGYMV resistance	Costa Rica	Zamorano, INTA
Bellagio	No. 201100450	cranberry, good postharvest quality	USA	MSU, USDA-ARS
Centenario		large red mottled bean, bush type architecture, resistance to anthracnose, angular leaf spot, rust and root rots	Ecuador	INIAP, MSU
Desert Song Flor de Junio		flor de junio bean, upright architecture, drought tolerance	USA, Mexico	MSU, USDA-ARS
El Dorada		pinto, upright architecture suitable for direct harvest	USA	MSU, USDA-ARS
Gypsy Rose Flor de Mayo		flor de mayo bean, upright architecture, drought tolerant, adapted to temperate climates	USA, Mexico	MSU, USDA-ARS
INTAD		purple mottled bean, resistance to anthracnose, angular leaf spot and root rots	Ecuador	INIAP, MSU
Lunga		purple bean, erect bush architecture, strong stem, high yield	Zambia	ZARI, SABRN, MSU
Lungwebungu		sugar bean, broad disease resistance, demanded by processing industry	Zambia	ZARI, SABRN, MSU
Mbereshi	NUA 45	Kabulangeti bean type, high Fe and Zn content,	Zambia	ZARI, PABRA, MSU
NABE 12C		common bean, excellent canning quality	Uganda	NaCCRI-Uganda, USDA-ARS, MSU, CIAT
NABE 16		common bean, excellent canning quality	Uganda	NaCCRI-Uganda, USDA-ARS, MSU, CIAT
NAROBEAN 1	RWR 2154 (submitted for varietal release)	early maturing (60-80 days), high Fe and Zn	Uganda	NaCCRI-Uganda, CIAT
NAROBEAN 2	RWR 2245	early maturing (60-80 days), high Fe and Zn	Uganda	NaCCRI-Uganda, CIAT
NAROBEAN 3	MOORE 88002	early maturing (60-80 days), high Fe and Zn	Uganda	NaCCRI-Uganda, CIAT
Powderhorn		Great northern, upright architecture, suitable for machine harvest	USA	MSU, USDA-ARS
Rojo del Valle		red mottled bean, buch type, resistance to anthracnoes, angular leaf spot, rust and root rots	Ecuador	INIAP, MSU
Rosetta		pink bean, upright architecture, suitable for direct harvest	USA	MSU, USDA-ARS
(submitted for varietal release)	SEN 98	common bean, drought tolerant, broad foliar disease resistance, high yield potential	Uganda	NaCCRI, CIAT, MSU
(submitted for varietal release)	SCR 26	common bean, drought tolerant, broad foliar disease resistance, high yield potential	Uganda	NaCCRI, CIAT, MSU
(submitted for varietal release)	SCN 11	common bean, drought tolerant, broad foliar disease resistance, high yield potential	Uganda	NaCCRI, CIAT, MSU
Santa Fe	No. 2001000269	pinto, broad disease resistance	USA	MSU, USDA-ARS
Snowdon		white kidney bean, early season, high yield	USA	MSU, USDA-ARS
Verano		heat tolerant white bean with resistance to BGYMV, common blight and BCMV	Puerto Rico	UPR, USDA-ARS

VARIETAL NAME	LINE OR PVP NO.	MARKET CLASS AND UNIQUE TRAITS	BENEFICIARY COUNTRY(S)	PARTNER INSTITUTIONS
Zorro	No. 201000268	small black, upright architecture, high yield potential	USA, Guatemala	MSU, USDA-ARS
Tepary Bean (Phaseoulus acutifolius)				
	TARS-Tep 22	white tepary, rust & CBB resistance, heat and drought tolerance, seed weevil resistance	Central America, Caribbean	USDA/ARS, UPR
	TARS-Tep 32	yellow tepary, heat and drought tolerance, common bacterial blight resistance	Central America, Caribbean	USDA/ARS, UPR
Lima Bean (Phaseolus lunatus)				
Beseba		BGYMV, heat tolerant	Haiti, Honduras	UPR, MoA Haiti, Zamorano
Cowpea (Vigna unguiculata)				
ISRA-3006		speckled black seed (Mougne type), early maturity	Senegal	ISRA-Senegal, URC
Kelle		white grain, large seeded	Senegal	ISRA-Senegal, URC
Leona		white grain, large seeded	Senegal	ISRA-Senegal, URC
Lisard		white grain, large seeded	Senegal	ISRA-Senegal, URC
Pakau		black eye grain, thrips resistant	Senegal	ISRA-Senegal, URC
Sam		white grain, large seeded	Senegal	ISRA-Senegal, URC
Thieye		white grain, large seeded	Senegal	ISRA-Senegal, URC
Melakh (new improved)		Striga resistant, early maturity	Senegal	ISRA-Senegal, URC
Four new varieties with projected release in 2018		white grain, Striga resistance, farmer preferred selections	Bukina Faso	INERA-Burkina Faso, UCR
IT98K-205-8	IT98K-205-8	blackeye grain, high yield, Striga resistance	Bukina Faso	INERA-Burkina Faso
KVx421-2	KVx421-2	blackeye grain, high yield, Striga resistance	Burkina Faso	INERA-Burrkina Faso
Melakh		light brown grain, early maturity, brought from Senegal	Burkina Faso	INERA-Burkina Faso
KVx442-3-25		large white grain, Striga resistance, high yield	Burkina Faso	INERA-Burkina Faso
CB50		large brighter white blackeye grain	USA	UCR
New cowpea lines		blackeye grain type, aphid resistance, nematode and wilt resistance	USA (projected release in 2018)	UCR
Common Bean Cultivars developed by Participatory Plant Breeding				
Arbolito Negro Mejorado	SJC 739-89	small black, BGYMV, BCMV & rust resistant, high altitude adaptation	Honduras	Zamorano, UPR
Amilcar 58	IBC 308-24	small red, heat tolerant, BCMV and BGYMV resistance, PPB	Honduras	Zamorano, FIPAH, CIALs
Briyo AM	IBC 306-95	small red, BCMV and BGYMV resistance	Honduras	Zamorano, CPRR, CIALs
Campechano JR	SX14825-7-1	small red, drought tolerant, BCMV & BGYMV resistance	Honduras	Zamorano, CIAT, PRR, CIALs
Chepe	703-SM15216-11-4-VR	small red, drought tolerant, BCMV resistance	Honduras	Zamorano, CIAT, FIPAH, CIALs
Don Cristobal	SRC1-12-1-8	small red, BCMV & BGYMV resistance	Honduras	Zamorano, CIAT, PRR, CIALs
Don Kike	MDSX14797-6-1	small red, BCMV & BGYMV resistance	Honduras	Zamorano, CIAT, PRR, CIALs
La Majada AF	IBC 301-182	small red, BCMV & BGYMV resistance	Honduras	Zamorano, PRR, CIALs
Marcelino	EAP 9508-41	small red, BCMV & BGYMV resistance	Honduras	Zamorano, FIPAH, CIALs
Milagrito	F0243	small red, BCMV resistant	Honduras	Zamorano, PRR, CIALs
Paisano PF	MER 2212-28	small red, heat tolerant, BCMV & BGYMV resistance	Honduras	Zamorano, PRR, CIALs
Victoria	SRS 56-3	small red, BCMV & BGYMV resistance	Honduras	Zamorano, PRR, CIALs

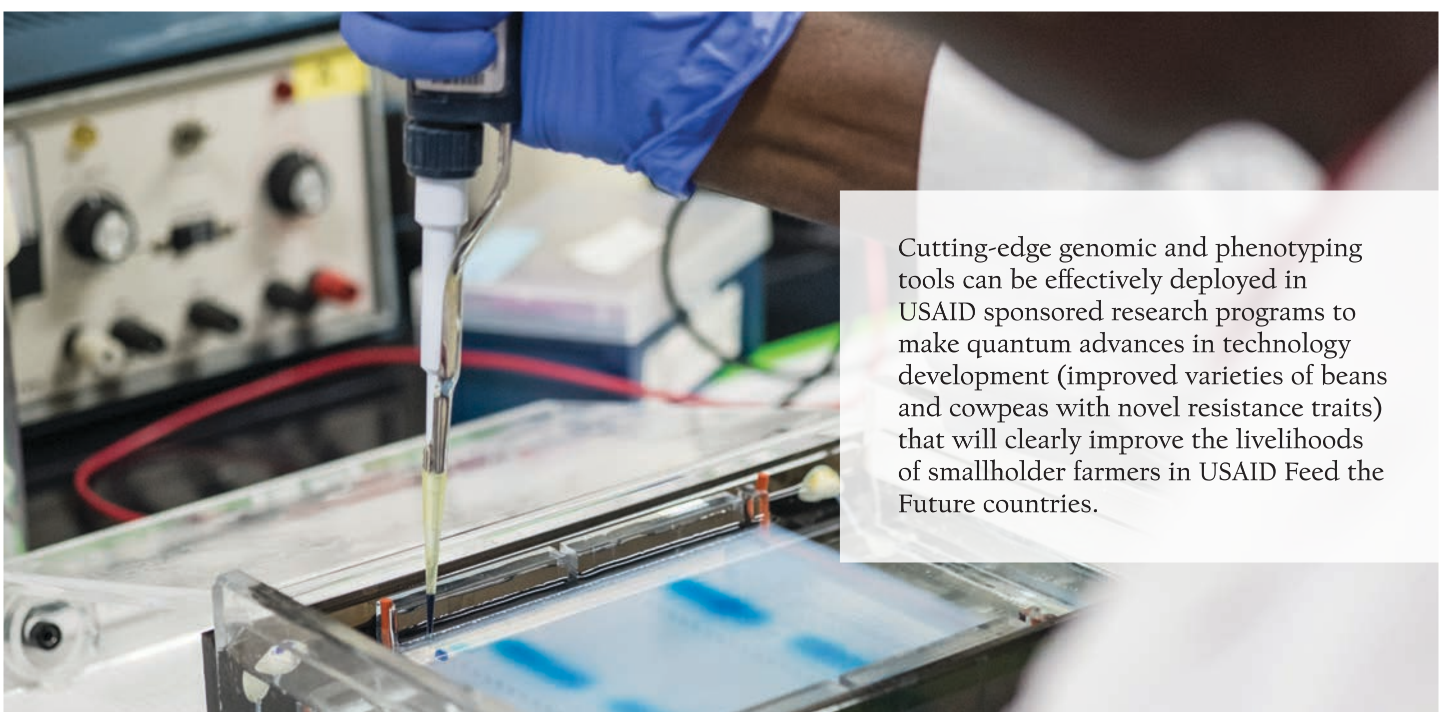
Advances in Genomics and Phenomics Transform Bean and Cowpea Breeding {B2}

Genetic improvement and breeding have undergone a dramatic transformation within the past decade. The Dry Grain Pulses CRSP (2007-2012) and the Feed the Future Legume Innovation Lab (2013-2017) program took advantage of this transformation by integrating the use of molecular genomic tools and technological advances in phenotyping into grain legume breeding programs. These technologies have enabled grain legume breeders to dramatically improve the efficiency of their breeding efforts especially for multi-genic traits, to discover novel new genes especially for physiological traits not previously possible, to combine genes within an individual line to achieve more durable or a broader spectrum of resistances to biotic and abiotic stresses, and to reduce breeding time and size of breeding populations for more efficient use of resources when developing new varieties.

Due to the partnership with U.S. universities who are working at the cutting edge of science, these advanced genomic and phenomic technologies were made available to and effectively utilized by bean and cowpea geneticists and breeders in national agriculture research organizations and agriculture universities in Feed the Future countries to achieve the breeding objectives of the DGP CRSP and LIL programs.

Perhaps the most significant genetic tool utilized on a regular basis by developing country breeders has been "molecular markers" and their application for marker assisted selection (MAS) and multiple gene pyramiding in crop breeding. Although different genetic marker tools are available to breeders, SNPs (single nucleotide polymorphisms) and Indels (single base deletions or insertions) are the two DNA- based molecular markers of choice that have been adopted in LIL projects. Specifically, they identify physical map positions of traits, are relatively easy to use, require only a small amount of DNA, provide highly reproducible results and can be used with precision to select a parent and to make a cross when one or both parents possess the DNA marker allele(s) for the desired trait.

SNP-genotyping platforms and the necessary associated genotyping services are available for common bean and cowpea on an out-sourcing basis, making them available to all partner institutions. These platforms include genetically mapped, genome-wide sets of markers which can be used in foreground selection using markers flanking the target trait, and at the same time in background selection for regaining the desired genotype of the recurrent parent. This is especially efficient when improving a preferred elite variety by adding one or more traits such as disease resistance without changing the variety background. Furthermore, the genome-wide design of these marker systems, with markers distributed across all chromosomes, enables selection of multiple target traits simultaneously, a key advantage for



Cutting-edge genomic and phenotyping tools can be effectively deployed in USAID sponsored research programs to make quantum advances in technology development (improved varieties of beans and cowpeas with novel resistance traits) that will clearly improve the livelihoods of smallholder farmers in USAID Feed the Future countries.

GENETIC TECHNOLOGY	TYPE	TRAIT	CROP SPECIES AND GERMPLASM	PARTNER INSTITUTIONS
Genetic characterization	24k SNP markers	race "Guatemala" identified	Middle American climbing bean germplasm collections–Guatemala	NDSU, ICTA-Guatemala
Molecular markers	107k SNPs	population characterization	Middle American climbing bean germplasm collections–Guatemala	NDSU, ICTA-Guatemala
Molecular marker	SNP	altitude adpatation	Middle American climbing bean germplasm collections–Guatemala	NDSU, ICTA-Guatemala
Molecular marker	SNP	seed shape	Middle American climbing bean germplasm collections–Guatemala	NDSU, ICTA-Guatemala
Molecular marker	SNP	anthracnose resistance	Middle American climbing bean germplasm collections–Guatemala	NDSU, ICTA-Guatemala
Molecular marker	SNP	bean rust resistance	Middle American climbing bean germplasm collections–Guatemala	NDSU, ICTA-Guatemala
Molecular marker	SNP	seed luster	Middle American climbing bean germplasm collections–Guatemala	NDSU, ICTA-Guatemala
Molecular marker	SNP	ascochyta resistance	Middle American climbing bean germplasm collections–Guatemala	NDSU, ICTA-Guatemala
Molecular marker	SNP	pod shape	Middle American climbing bean germplasm collections–Guatemala	NDSU, ICTA-Guatemala
Mode of Inheritance	genes	rust resistance	Andean bean genotypes	NaCCRI-Uganda, MSU, UNL
Mode of Inheritance	genes	BCMV & BCMNV resistance	Ugandan Andean bean genotypes	NaCCRI-Uganda, MSU
Mode of Inheritance	genes	Common Bacterial Blight (CBB) for leaf and pods	Ugandan Andean bean genotypes	NaCCRI-Uganda, MSU
Molecular marker	Codominant Indel	bruchid resistance	tepary and common bean	UPR, NDSU
Molecular markers (8)	KASP	rust resistance in Uganda	common bean	MSU, NaCCRI-Uganda
Molecular markers	SNP	angular leaf spot	common bean	USDA-ARS
Molecular markers	SNP	symbiotic nitrogen fixation	common bean	USDA-ARS, MSU
Molecular marker	SNP	phytochrome flowering gene on Pv01 chromosome	common bean	USDA-ARS, MSU
Molecular marker	SNP	grain yield on Pv03 chromosome	common bean	USDA-ARS, MSU
Quantitative Trait Loci (QTL) (3)		aphid resistance	cowpea	URC
QTLs mapped (2)		rootknot nematode resistance	cowpea	UCR
QTLs mapped (3)		fusarium wilt resistance	cowpea	UCR
Molecular markers (3)	SNP	aphid resistance	cowpea	UCR
Molecular markers (2)	SNP	rootknot nematode resistance	cowpea	UCR
Molecular markers (3)	SNP	fusarium wilt resistance	cowpea	UCR
Molecular markers	SNP	drought tolerance	cowpea	UCR
Cowpea SNP Genotyping Platform	Goldengate SNP genotyping assay (1100 mapped SNPs)		cowpea	UCR
Cowpea aphid biotype resistance differential panel		aphid resistance screening	cowpea	URC, INERA-Burkina Faso, ISRA-Senegal, SARI-Ghana
QTLs mapped	Phenotyping in DEPI chambers	high and low temperature responses	cowpea	MSU, UCR
QTLs mapped	PhotosynQ phenotyping in field	drought tolerance (photosynthetic efficiency)	common bean (in Zambia)	UNZA, MSU
QTLs mapped (2)	DEPI and PhotosnQ field phenotyping	Heat tolerance (chlorophyll content and photo-protection)	cowpea	MSU, UCR
QTLs mapped (2)	DEPI and PhotosnQ field phenotyping	Cold tolerance (lipid membrane and ATP synthase for photosynthetic efficiency)	cowpea	MSU, UCR
Molecular markers (15)	SNP	bean rust resistance in Uganda	common bean	MSU, NaCCRI-Uganda
Genes annotated	Phvul.002G008400, Phvul.002G010100, Phvul.002G010100, Phvul.002G011500, Phvul.003G187200, Phvul.003G294300, Phvul.005G018800, Phvul.005G058200, Phvul.005G114400, Phvul.009G034600	bean rust resistance in Uganda	common bean (Andean type)	MSU, NaCCRI-Uganda

TABLE 3. Genomic technologies developed by Legume Innovation Lab projects

Collaborating scientists in national agriculture research organizations and universities in developing countries can be trained to effectively use modern advanced genomic (SNP and Indel markers, MAS) and phenotyping (MultispeQ and PhotosynQ) tools in their research programs.

breeders in combining traits controlled by multiple genetic determinants. These new genetic marker systems and their breeding application have provided excellent degree and post-degree training opportunities for both young and experienced host-country NARO scientists, via short-term workshops, degree programs and active research and breeding program efforts.

Table 3 summarizes some of the important molecular (SNP and Indel) markers that have been developed through DGP CRSP and LIL projects. These markers are for important resistance traits to diseases (bean rust, BCMV, BCMNV, CBB, fusarium wilt, ashy stem blight or charcoal rot, ALS) and insect pests (bean weevil/bruchid, aphid) and nematodes (root knot). In addition, markers have also been identified for abiotic stress responses such as drought and high temperature tolerance, and for high symbiotic nitrogen fixation in grain legumes. Markers for unique traits such as altitudinal adaptation and seed shape were also developed.

Leadership for the genomic research and marker discovery in the LIL program was provided by Drs. Phil McClean and Juan Osorno (North Dakota State University), James Kelly (Michigan State University) and Phil Miklas and Tim Porch (USDA-ARS) for common bean, and by Drs. Phil Roberts and Tim Close (University of California Riverside) for cowpea.

> The genome-wide design of marker systems, with markers distributed across all chromosomes, enables selection of multiple target traits simultaneously, a key advantage for breeders in combining traits controlled by multiple genetic determinants.

The value of the genetic markers for economically important traits in common bean and cowpea developed through USAID sponsored DGP CRSP and LIL projects to grain legume breeding programs worldwide is boundless. As a result of the publication and sharing of these molecular markers, bean and cowpea breeding programs both in the U.S. and around the globe are regularly utilizing these markers to make crosses and select progeny and lines that combine important traits needed to achieve breeding objectives. The ultimate impact of these molecular markers will be ongoing as research institutions in developing country strengthen their capacities in molecular genetics and become more internationally networked.

The ability to screen germplasm and effectively measure phenomes for morphological, developmental, biochemical, and physiological traits of individual plants or lines is essential to developing good molecular genetic markers. Most phenotypic characterization has been conducted historically through labor intensive manual screening and measurement of plants in growth chambers or in controlled field trials. In addition to being time consuming and costly, such methods are weak in the discovery of genes for important biochemical or bio-physical (e.g., carbon fixation, stomatal conductance, leaf temperature) traits in plants. These traits are particularly important for genetic improvement of grain legumes for tolerance to abiotic stresses and for improving the genetic yield potential of a crop.

The Legume Innovation Lab invested in the development of an innovative low-cost handheld meter, "MultispeQ", that could be used by breeders in Feed the Future countries to phenotype grain legumes for physiological traits under field conditions and obtain high quality reproducible data. This project, led by Dr. David Kramer at Michigan State University, incorporates sophisticated analytical instrumentation into a miniaturized device for measurement of diverse physical parameters of leaves and canopies of plants that are directly associated with physiological traits associated with photosynthesis, carbon assimilation and transport, evapotranspiration, and a range a plant responses to plant water deficit and temperature extremes. The devices are wirelessly connected to a cloud-based platform called PhotosynQ (www.photosynq.org) that enables local users to rapidly analyze their data, making predictions of crop status and identifying quantitative trait loci (QTL) associated with these important traits. With QTLs, breeders will be able to effectively enhance yield and adaptation to specific environments where beans and cowpea are grown.

With Legume Innovation Lab support, the following applications of the MultispeQ and PhotosynQ platform have been developed for improving the effectiveness and efficiency of bean and cowpea breeding.

- Determination of ideal environmental conditions for phenotyping and discovery of key abiotic adaptation and/or tolerance traits. For example, unique photosynthetic phenotypes were easier to identify under fluctuating light irradiance levels and high day and night temperature regimes.
- Field measurements utilizing the PhotosynQ platform were demonstrated to be highly correlated with controlled environment phenotyping results and thus valuable for phenotyping large numbers of lines with a high degree of efficiency and trait resolution.

- Mapping of QTL in controlled high and low temperature conditions demonstrates the ability to rapidly identify key adaptive or tolerance traits and thus significantly reduce the breeding time for the development of elite grain legume breeding lines.

Dr. Kramer's research team demonstrated a commitment to building human resource and institutional capacity in the use of this advance phenotyping platform. Dr. Kelvin Kamfwa, UNZA-Zambia, provided leadership to the mapping of QTL for drought in common bean under local field conditions, and LIL sponsored PhD candidates Isaac Osei-Bonsu from Ghana and Donghee Hoh, S. Korea, for the physiological QTL associated with drought and both heat and low temperatures in common bean and cowpea respectively. In addition, six MultispeQ units were provided to the University of Zambia and five to Makerere University in Uganda along with training and mentoring of technicians on their use in crop improvement.

The take-home lesson from the FTF Legume Innovation Lab experience is that U.S. university and USDA-ARS scientists can effectively deploy cutting-edge genomic and phenotyping tools in USAID sponsored research programs to make quantum advances in technology development (improved varieties of beans and cowpeas with novel resistance traits) that will clearly improve the livelihoods of smallholder farmers in USAID Feed the Future countries. The accompanying lesson is that collaborating scientists in national agriculture research organizations and universities in developing countries can be trained to effectively use modern advanced genomic and phenotyping tools in their respective research programs. Perhaps one of the greatest legacies of the DGP CRSP and the LIL programs will be the capacity strengthening of bean and cowpea programs in Africa and Latin America to utilize 21st century research technologies to better serve the needs and challenges of the emerging agro-industries in their respective countries.

Regional Bean Breeding Strategy for Lowland Tropics of Central America and the Caribbean pays Big Dividends {B3}

Throughout the performance period, the team of Beaver and Rosas developed and released over 60 common bean varieties for the low land tropics in the Central America/Caribbean region including 23 varieties during the past 10 years (Table 2).

The production and consumption of grain legumes are not defined by national borders. Agro-ecologies and common cropping systems that incorporate a grain legume crop typically in association or rotation with a cereal are found in distinct multi-country regions of the world. Examples of regions with a common legume-based production system include the cowpea-sorghum system in the Sudano-savanna area of Western Africa (Ghana, Burkina Faso, Mali, northern Benin, northern Nigeria), the Andean common bean-maize system in the Andean region of South America (Colombia, Ecuador, Peru, Bolivia) and the Meso-American bean-maize system in middle America (Mexico, Guatemala, Honduras, Nicaragua, El Salvador, Costa Rica and Panama) and the Caribbean (Haiti, Dominican Republic and Cuba). Production constraints are often regional in scope as evidenced by the devastating losses to the maize crop in Africa caused by the fall armyworm.

Engagement with individual institutions in multiple countries to achieve coordinated regional impact is a challenge because of limitations in resources and the selection of Feed the Future "focus countries" by the U.S. government that are not strategically positioned nor have the capacity to lead a regional research and development effort.

The approach of the Dry Grain Pulses Collaborative Research Support Program (CRSP) (2007-2012) and the FTF Legume Innovation Lab (2013-2017) was to identify an advanced research institution within an FTF focus country in a priority region for a grain legume commodity and to develop a research agenda that would benefit grain legume value chains within a region that may encompass multiple countries. The good fortune of the DGP CRSP and LIL programs was that they were able to identify principle investigators and institutions which shared this vision and were committed to serving a commodity sector and value-chains that extend beyond any one national boarder.

The partnership between Dr. James Beaver, University of Puerto Rico, Mayaquez Campus, and Dr. Juan Carlos Rosas, Escuela Agricola Panamericana- Zamorano in Honduras, is an example of a successful long-term collaborative relationship that has generated technologies and trained a generation of common bean breeders that have benefitted six countries in Central America (Honduras, El Salvador, Nicaragua, Guatemala, Costa Rica and Panama) and Haiti in the Caribbean. This relationship began with support from the Bean/Cowpea CRSP in the late 1980s and was extended through both the DGP CRSP and FTF LIL program phases.

Keys aspects contributing to the regional success of the Beaver – Rosas' research collaboration were:

- Provide strong scientific and technical research leadership to breeders of the region and coordinate research and training activities
- Identify game-changing research priorities that would benefit farmers throughout the region
- Engage NAROs within the region at all stages of technology development, validation and deployment
- Enable partner NAROs to have ownership of technological outputs

- Commitment to the training of scientists, technicians and industry leaders to serve all countries in the region

The game-changing research agenda for genetic improvement of common bean by Drs. Beaver and Rosas' breeding programs during the DGP CRSP and LIL phases includes:

- Breed durable resistance to bean golden yellow mosaic virus (BGYMV) and bean common mosaic necrotic virus (BCMNV), common bacterial blight, and angular leaf spot resistance into Meso-American small red and black bean varieties
- Identify and introgress genes for resistance to web blight and greater tolerance to high temperatures into common bean varieties
- Introgress resistance to the common bean weevil into several common bean market classes important for household food security within Central America and Caribbean
- Genetically improve tepary bean (*Phaseolus acutifolius*) for production in high temperature areas and seasons prone to drought stress

Bean golden yellow mosaic virus (BGYMV) is a widespread disease within the lowland production areas of Central America and the Caribbean responsible for up to 90% reductions in grain yield within affected areas. This gemini-virus has a wide array of plant hosts including several crops and weeds and is readily transmitted by the white fly insect vector. BGYMV is responsible for food insecurity in countless rural households in the region. During the 1980s and 1990s, Drs. Beaver and Rosas played crucial roles in elucidating the inheritance of BGYMV resistance and developing BGYMV resistant breeding lines in different market classes in collaboration with CIAT-Guatemala, the U. of Wisconsin and NAROs. Since those early days, the team with USAID support has been committed to breeding BYGMV resistance genes in combination with genes of BCMV and BCMNV resistance into all common bean cultivars developed for the lowland tropics region of Central American and the Caribbean. Evidence of this effort are the releases of several high yielding varieties that combine important abiotic and biotic resistance genes including resistances for BGYMV, BCMV and BCMNV. Examples of varieties that have been released in multiple countries with high potential regional impact include: (See Table 2, page 15)

- "Azabache" and "Sankara", line XRAV-40-4, released in both Honduras and Haiti, respectively, a small black seeded variety, multiple virus resistances

- “Lenca Precoz”, line MEN2201-64ML, released in both Honduras and Haiti, small black seed, early maturity, multiple virus resistances
- “CENTA EAC” and “Rojo Chortí”, line SIC-730-79, released in both El Salvador and Honduras, respectively, small red seed, heat tolerance, multiple virus resistances
- “PRO806-81”, released in several Central American and Caribbean countries, small white seed, multiple virus resistances, pyramided genes for rust resistance

Web blight (*Rhizoctonia solani*), a wide-spread and difficult to control soil-borne disease of common bean in humid tropical production areas, has also been a focus of the Beaver and Rosas collaborations during the last 10 years. Breeding for genetic resistance in beans is complicated by the fact that numerous isolates of the pathogen exist which vary in virulence. Four cycles of recurrent selection for web blight resistance were conducted to combine different sources of genetic resistance to achieve more durable resistance, especially when a bean variety is to be grown throughout the Central American and Caribbean region. Recent observations of possible independent control of seed quality and the foliar response to web blight may help to broaden the base of resistance to this disease. An output of their collaborative efforts has been the release of advanced breeding lines of bean (PRO401-259 and PRO-650-31) with high levels of resistance to web blight combined with common bacterial blight resistance and resistance to BYGMV and BCMV (See Table 1, page 11).

> This pyramiding of resistance to individually complex disease resistance traits is an extraordinary achievement.

In addition they have identified other cultivars, germplasm, and breeding lines with useful levels of resistance to web blight including Amadeus 77, PR 1147-1, and TARS-MST1.

The common bean weevil, a bruchid (*Acanthoscelides obtectus Say*), is a major problem for the postharvest storage of common bean grain and thus a threat to household food security in Central America. Drs. Beaver

Dry Grain Pulses Research Brief (July 2012)
Improved bean varieties in Central America and Ecuador generate economic benefits to farmers

B. Reyes,M. Maredia and R. Bernsten

Between 1990 and 2010, the National Agriculture Research Systems (NARS) in Honduras, El Salvador, Nicaragua, Costa Rica, and Ecuador, in collaboration with international partners such as the Bean/Cowpea and Dry Grain Pulses CRSPs and CIAT, have released 90 improved bean varieties, some in more than one Central American country.

In 2010, improved varieties represented 67 percent of the small red bean area in Central America and 50 percent of the red mottled bean production area in Ecuador.

Amadeus 77, a small red seeded variety developed by Dr. Juan Carlos Rosas at the Escuela Agricola Panamericana Zamorano in Honduras with Bean/Cowpea and DGP CRSP funding, was widely adopted and accounted for approximately 50% of the total areas harvested with beans in 2010 among the Central American countries

Research investments to develop these improved varieties have generated a regional net present value of US$359 million and an internal rate of return of 32 percent.

and Rosas took advantage of the development of interspecific lines between common and tepary bean (*P. acutifolius*) made by Oregon State University (OSU) and Sokoine University of Agriculture (SUA) under a Bean/Cowpea CRSP project (2002-2006). The Tepary bean parent was known to be resistant to this species of bruchid. Interspecific lines were used to introgress bruchid resistance into various seed market classes of beans grown in Central America and the Caribbean. The resulting lines were tested with different bruchid biotypes and species to validate the stability of the resistance in multiple countries. They are also collaborating with other geneticists to develop breeder friendly molecular markers for bruchid resistance. This seminal research on bruchid resistance will be a game-changer for smallholder farmers in the region that depend of on-farm bean production to provide for household consumption throughout the year by dramatically reducing storage losses.

This seminal research on bruchid resistance will be a game-changer for smallholder farmers in the region that depend of on-farm bean production to provide for household consumption throughout the year by dramatically reducing storage losses.

Dr. Rosas has showed leadership in the Central America and Caribbean region by coordinating several regional nurseries which provide opportunity annually for the multi-locational testing of elite lines from the EAP-Zamorano, UPR, CIAT and USDA-TARS bean breeding programs in partnering countries within Central America and the Caribbean. In addition, the DGP CRSP and LIL projects have convened regular Regional Bean Research Workshops involving bean breeders and technicians from countries in Central America, Caribbean and Mexico to share advances in bean breeding and resistance gene discovery, evaluations of elite materials in different environments, ongoing production constraints and future breeding objectives. During the 2017 regional workshop held in Honduras, leaders of NAROs representing 11 institutions from nine countries presented the achievements of each bean research program in the genetic improvement of common bean and discussed future research priorities and institutional strengthening needs for the region.

This regional leadership and coordination would likely not have occurred without the long-term support provided by USAID through the DGP CRSP and LIL program to the breeding programs of Drs. James Beaver and Juan Carlos Rosas and their shared commitment to collaboration.

Tepary Bean – A Novel Technology Improves Resilience to Drought and High Temperature environments {B4}

Faced with increasing risk of severe droughts and high temperatures, farmers in the lowland tropics of Central America, the Caribbean and Sub-Saharan Africa are faced with few options: either stop growing common bean or plant varieties that better tolerate these abiotic stresses. The common bean (*Phaseolus vulgaris*) is best adapted to semi-temperate conditions, as represented by their native habitats in the highlands of Central and South America, and not to hot semi-arid tropical climates. The increased frequency of terminal or intermittent drought in many agricultural areas is contributing to yield reductions and thus to food and nutritional insecurity in affected regions. Since grain legumes are both staple and cash crops for smallholder farmers in many developing countries, technologies and integrated crop management practices need to be developed to improve the resilience of farmers to drought and heat stresses.

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International genetic improvement and breeding research on common bean to increase tolerance to low soil moisture has been successful. Moderate levels of drought tolerance can be achieved by breeding for early and determinate plant architecture, the selection of deep-rooted varieties that escape the pending stress conditions and the identification of bean lines that are more efficient in using available water to produce seed yield under drought stress. Greater tolerance to high temperatures have been achieved by selecting common bean lines with reduced reproductive abscission, better pollen viability and germination, and improved seed fill under high ambient conditions during reproductive development. There are, however, limits to the tolerance of common beans to high temperature and drought. The challenge has been to identify and introgress genes into common bean varieties that confer greater physiological adaptation to hot and dry environments.

Tim Porch [USDA/ARS- Tropical Agriculture Research Station (TARS)] with support from the Legume Innovation Lab project at the University of Puerto Rico has focused on breeding of *Phaseolus acutifolius* (tepary bean) as an alternative "bean" crop for areas in Central America and Haiti that may be too hot and dry for common bean.

Tepary bean is a sister species to common bean which was domesticated and cultivated for thousands of years by indigenous peoples in Central America, Mexico and the Southwestern United States. Due to the climatic conditions in this region, tepary bean landraces were selected with strong resistance to drought and high temperature. Tepary makes an ideal alternate bean crop because it offers a relatively diverse array of seed colors and has a favorable cooked flavor. White-seeded tepary bean appears similar to navy beans while black tepary looks much like small-black Mesoamerican beans grown in Guatemala. Although tepary has high yield potential, the limitation for commercial production and marketing, however, is its small seed size, poor agronomic traits, and lack of resistance to economically important diseases.

With joint funding from the FTF Legume Innovation Lab and a USDA/ARS Feed the Future bean improvement project, two improved lines of tepary bean were

developed and released (TARS-Tep 22 and TARS-Tep 32) with multiple stress-tolerance including heat and drought stress, resistances to bacterial blight and seed weevil, larger seed size and a more erect plant architecture. It is noteworthy that TARS-Tep 22 represents the first published release of an improved tepary bean line as a result of hybridization and selection.

Major genetic gains have also been made in tepary bean using modern genomic tools.

- QTL (quantitative trait loci) have been identified for abiotic stresses, CBB resistance, Biological Nitrogen Fixation (BNF), and BCMV and BCMNV resistance through QTL evaluation of a tepary recombinant inbred line population (RIL) and GWAS of the Tepary Diversity Panel. BCMV is a major constraint for tepary bean producers in the U.S.

- Single tepary bean plant selections with tolerance to BGYMV and resistance to BCMV and BCMNV have been advanced and are being crossed to pyramid these resistances. Since the sources of these resistances are photoperiod sensitive and/or are wild tepary beans with small seed size, breeding is being conducted to improve these traits.

- Tepary bean adaption trials conducted in Honduras, Guatemala, Nicaragua, El Salvador, Tanzania and Burkina Faso show great promise and acceptability of tepary by farmers.

Current efforts are to establish a collaborative tepary bean genome sequencing consortium to produce the first reference genome of *Phaseolus acutifolius* using a parent of a RIL population, G40001, as a reference genotype. The tepary bean genome is expected to lead to the identification and characterization of the genetic and physiological basis for heat and drought tolerance along with other traits. With the recent discovery by a CIAT scientist of a *Phaseolus vulgaris* line that is cross-fertile with tepary bean, interspecific hybrids can now be developed without embryo rescue techniques.

The future is therefore bright! Robust heat and drought tolerance genes identified in *P. acutifolius* will be introgressed into common bean varieties with high yield potential.

In addition, the improved tepary bean varieties that are released in the future will find their production niche in semi-arid areas where smallholder farmers have limited access to irrigation and thus depend on rain-fed agriculture for their livelihoods and food security.

Legume Innovation Lab scientists have clearly demonstrated international leadership in the genetic improvement of beans to improve smallholder farmer resilience to extreme weather events and reoccurring droughts.

The Potential of Biologicals for Sustainable Management of Insect Pests in Cowpea Cropping Systems {B5}

The frustrating challenge of smallholder cowpea farmers in Western African countries is to control a diverse array of insect pests that limit cowpea yield. Although the genetic yield potential of improved cowpea varieties ranges from two to three metric tons per hectare when grown under ideal conditions, average farm cowpea yield in West Africa is only 240 kg/ha. This is unacceptably low and contributes to household food, nutritional and economic insecurity in the region. The obvious question, therefore, is why can't farmers control the insect pests through the use of chemical insecticides? The response to this question is complex. The simple reason, however, is that resource-poor farmers don't have access to affordable, effective and environmentally safe insecticides for application on cowpeas at critical times during the production season. Additionally, numerous studies have demonstrated high human health risks of cheap insecticides of doubtful quality to users that are being marketed in agricultural supply stores throughout Africa. The composition of chemical ingredients in the pesticide formulations are frequently unknown or falsified (inaccurate labels), which is contributing to both severe health risks to applicators due to toxic compounds not declared on the label plus poor effectiveness in controlling insect pests.

> Resource-poor farmers don't have access to affordable, effective and environmentally safe insecticides for pest control in cowpeas.

The challenge of insect pest management (IPM) in cowpeas has also been exacerbated by the failure to breed insect resistant cowpea varieties. Although transgenic cowpea lines with the *Bt* gene for resistance to cowpea pod borer, *Maruca vitrata*, have been developed, the timeline for release of and farmer access to these varieties and farmer willingness to plant and consume a GMO crop make their future use uncertain. Moreover, the new transgenic varieties would only control one of the numerous insect pests attaching cowpeas in West Africa. Other economically important pests include the coreid pod-bugs (*Clavigralla tomentosicollis Stal* and *Anoplocnemis curvipes*), the groundnut aphid (*Aphis craccivora* Koch.) and thrips (*Megalurothrips sjostedti* Trybom).

The Dry Grain Pulses CRSP and the FTF Legume Innovation Lab invested in the development of sustainable and environmentally safe integrated pest management (IPM) technologies based on the use of biologicals, and of strategies for scaling up of these technologies in a socially and economically acceptable manner for widespread regional impact. A research team led by Drs. Barry Pittendrigh (Michigan State University) and Manuele Tamo (IITA-Benin) and collaborators at INERA-Burkina Faso, INRAN-Niger, CRI-Ghana, SARI-Ghana and INRAB-Benin undertook the research challenge. Their work focused on understanding the biology of insect pests and their vulnerabilities and the development and field testing of diverse integrated management tools and approaches for pest control so as to provide cowpea farmers with options.

Major game-changing scientific achievements by this team, which demonstrate the viability of biological-based IPM strategies in smallholder cowpea cropping systems in West Africa, include:

1. Regional scouting and forecasting of *Maruca* pod borer infestation

Scientists in Benin, Burkina Faso, Niger and Ghana have scouted cowpea fields and monitored populations and geographic movements of both cowpea insect pests and beneficial insects over the past ten years. Molecular analyses using SNP and microsatellite markers were developed to identify the insect species attaching cowpea. By analyzing insects captured in traps and using computational models, the movement of insect populations and their infestation in cowpea fields can be forecast throughout the region. Monitoring has become a powerful tool for the development of appropriate IPM responses and pest control interventions by smallholder farmers. Educational SAWBO animations on IPM practices have been developed to guide cowpea farmers in making good pest control management decisions.

> Educational SAWBO animations on IPM practices have been developed to guide cowpea farmers in making good pest control management decisions.

2. Identification, rearing and release of novel parasitoid species for Maruca pod borer control

Two highly complementary and effective species of parasitoids for controlling *Maruca* pod borer in cowpea were identified in collaboration with WorldVeg in Taiwan, *Phanerotoma syleptae* and *Therophilus javanus*. Wasps of these two small beneficial parasitoids attack eggs and young caterpillars of *Maruca*, respectively, thereby killing *Maruca* caterpillars before they can do damage to cowpea flowers and young pods. The morphology and biology of *T. javanus* have been studied by the LIL PIs in order to better understand factors affecting parasitism of *Maruca* pod borer by the parasitoid.

To validate the effectiveness of these parasitoids in controlling pod borer in cowpea fields, tens of thousands of these two parasitoids were reared and released in Burkina Faso, Niger and Benin. Both parasitoids have been found approximately one year later in vegetation within an area up to 23 km from the release sites. This confirms that the parasitoid species have been able to survive the harsh dry season in the Sudano-savanna region and become naturalized. Preliminary data from multi-locational yield studies indicate that these beneficial parasitoids significantly reduce *Maruca* pod borer populations below economic threshold levels in cowpea fields (based on preliminary studies). The team is well poised for larger-scale deployment and impact studies.

The introduction of beneficial insects for pest control in cowpea, such as these two parasitic insect species (*T. javanus* and *P. syleptae*), represents a sustainable solution to the *Maruca* pod borer pest challenge facing cowpea growers. Since there is no direct cost to smallholder cowpea farmers, establishment of naturalized populations provides long-term ongoing control. The only hurdle will be for countries to support and coordinate mass releases of these parasitoid species throughout the West African cowpea production region.

With this scaling up goal in mind, LIL scientists have also developed a game-changing system for mass rearing of parasitoids plus a collapsible cage for mass field releases. These easy-to-use technologies can be readily deployed by extension and NGO technicians on a wide scale with limited cost. Moreover, the technology can be readily adapted for the rearing of other beneficial insects for pest control in developing countries.

3. Community-based production and use of the MaviMNPV virus in combination with emulsified neem oil extracts to control *Maruca* pod borer and thrips

LIL scientists have demonstrated that a combination of neem oil applied in combination with a solution containing the MaviMNPV virus to cowpea plants, at flowering, controls *Maruca* plus other pests and significantly increases cowpea grain yields, even higher than yields from fields in which traditional chemical insecticides had been applied. Neem oil, which has insecticidal properties, can be easily pressed from the nuts collected from an indigenous legume tree in West Africa. The MaviMNPV virus which specifically kills *Maruca* caterpillars was discovered in collaboration with scientists at WordVeg. The advantage of these two technologies is that they can be easily produced and marketed in rural communities, therefore generating new income opportunities for woman and farmer groups. The LIL project has supported training sessions of the MaviMNPV virus for womens groups in Benin and the construction of “village rearing labs” in cowpea producing localities in partnership with the Ministry of Agriculture who has oversight responsibility for biopesticides in Benin. For the first time, an affordable, highly effective and safe “biopesticide” is available for scale-up throughout West Africa to control insect pests in cowpeas. The LIL expects this to be a “game-changer.”

4. Other IPM Technologies for Cowpea

The desirability of research investments is that projects often result in unanticipated spinoff technologies. This is certainly the case in the cowpea IPM project. Several

unique findings which will likely provide additional IPM tools for smallholder farmers include:

a) A "tea bag" system containing a concentrated neem seed powder was developed by the LIL IITA-Benin team. These low-cost and easy to handle neem bags facilitate the measured preparation of small quantities of neem solution to be applied to small areas of cowpea.

b) A male aggregation pheromone for *Clavigralla*, a pod-bug pest species in cowpea, was discovered. Pheromones are chemical substances produced and released into the environment by an insect that affect the behavior or physiology of others insect species. In this case, the newly identified pheromone attracts parasitoids to the eggs of *Clavigralla*. This pheromone provides a tool to attract biocontrol agents (egg parasitoids) into fields early in the season to reduce injury caused by invading pod-bug populations.

c) An endophytic fungus species (*Beauveria bassiana*) was found to colonize cowpea plants in West Africa. LIL scientists observed that plants with the *B. bassiana* fungus experienced substantially less pest pressure including by *Maruca* pod borer. Since the lack of pest damage resulted in increased cowpea pod and grain production, LIL scientists believe that this discovery could lead to the development of another novel biocontrol for insect pests in cowpea.

d) Molecular markers for all major pest insects of cowpea have been developed, which have in turn been used to better understand pest populations' structures and movement patterns. Outcomes from these molecular marker studies led to better recommendations as to when and where to release biological control agents.

The Legume Innovation Lab has been a world leader in the development of biocontrols for the management of insect pests in cowpea production systems in Africa. LIL scientists believe that an integrated sustainable biocontrol approach based on the use of parasitoids, biopesticides (neem, MaviMNPV virus, *B. passiana* fungus, pheromones, etc.) plus insect resistant cowpea varieties is the future and provides hope to smallholder resource-poor cowpea farmers in Feed the Future countries.

Exploration of Novel Traits and New Gene Discovery have High Potential Payoff in Beans and Cowpeas {B6}

Genetic improvement of staple crops such as common bean and cowpea are dependent upon access to diverse germplasm, exploration of novel traits, discovery of new genes, and the ability to combine desired traits in complementary and synergistic ways to achieve specific breeding objectives. Smallholder resource poor farmers in developing countries have much to gain from genetic improvement because they lack access to the necessary inputs to manage the diverse array of biotic (diseases, insect pests) and abiotic (low soil fertility, drought, temperature extremes) constraints that limit grain yields.

> The Dry Grain Pulses CRSP and the Feed the Future Legume Innovation Lab recognized that investment in novel trait exploration and new gene discovery is essential for overcoming some of the most recalcitrant constraints to bean and cowpea productivity.

The Dry Grain Pulses CRSP and the Feed the Future Legume Innovation Lab recognized that investment in novel trait exploration and new gene discovery is essential for overcoming some of the most recalcitrant constraints to bean and cowpea productivity. Grain legume yields on smallholder farms in developing countries are unacceptably low, frequently only 20 to 40% of genetic yield potential, due largely to abiotic and biotic stress factors. In West Africa, low cowpea yields are directly attributable to infestation by various pod and leaf sucking insect pests. In humid bean production areas in Sub-Saharan Africa and Latin America, common bean yields are constrained by root rots and foliar pathogens. With many production areas experiencing temperature extremes and major weather events, new genes are needed to develop varieties that are tolerant to the associated abiotic stresses (high and low temperature, drought, etc.) and exhibit yield stability from one season to another.

The three following Legume Innovation Lab projects give evidence to achievements in the assessment of genetic diversity, exploration of new traits and the discovery of new genes in common bean and cowpea.

1. Genetic Improvement of Middle America Climbing Beans for Guatemala

A "milpa" system involving the intercropping of climbing beans and maize is common in the highlands of Guatemala and Southern Mexico. Within this system, Mayan farmers have selected and retained landraces of climbing common bean (*Phaseolus vulgaris*), scarlet

Molecular markers for novel traits have been identified in the Guatemala climbing bean germplasm collection including "resistances to Ascochyta Blight, Rust and Anthracnose, adaptation to low temperatures/high altitudes, assimilate partitioning, seed yield potential, and for pod distribution within a plant."

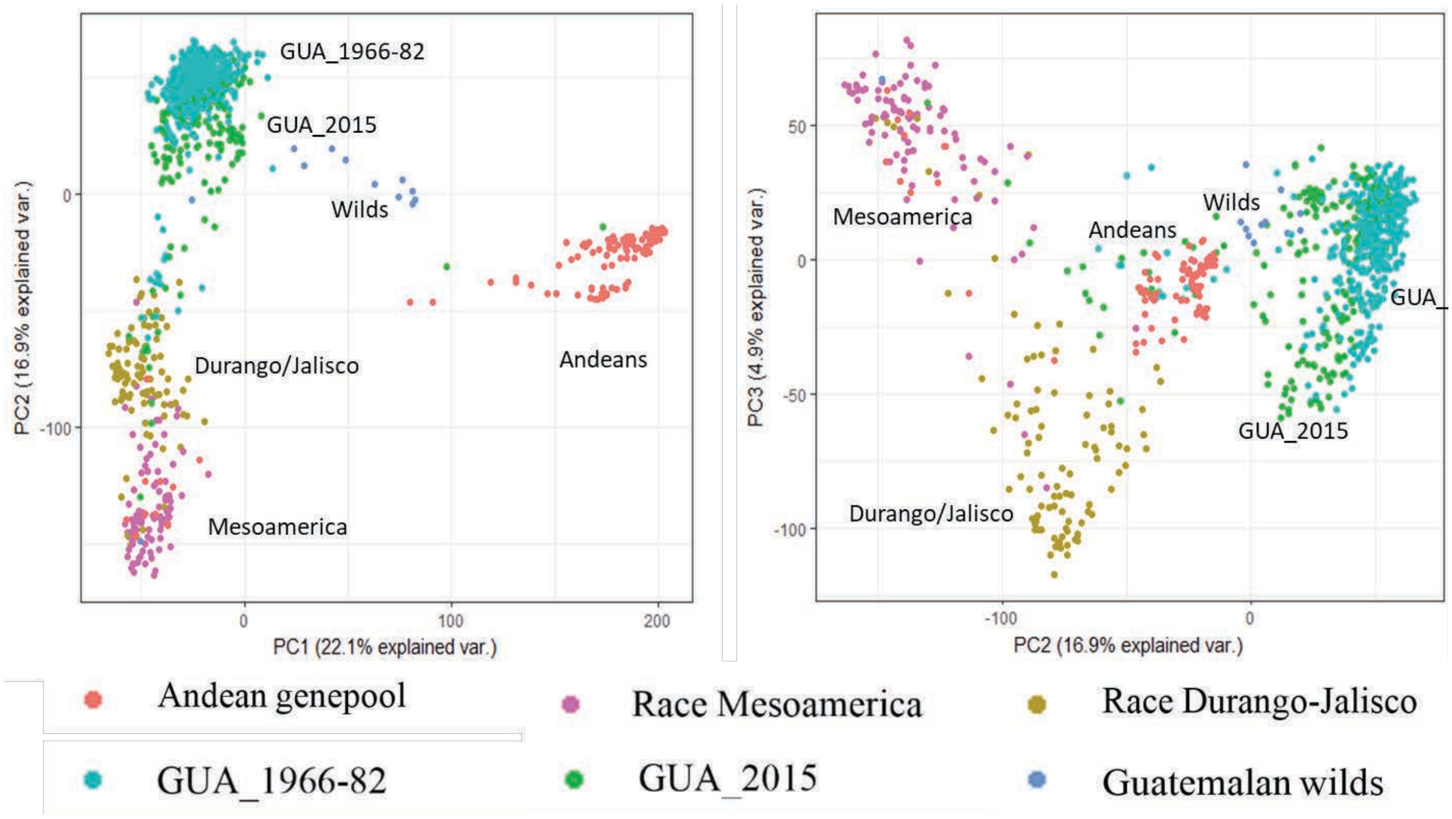


FIGURE 1. Principal component analyses showing groups of genetic diversity among different common bean collections. GUA_1966-82 represents an old climbing bean collection and GUA_2015 a new climbing bean collection from Guatemala obtained by ICTA scientists with support from the FTF Legume Innovation Lab.

runner bean (*P. coccineus*) and a large seeded "piloy" bean (*P. polyanthus*). The enigma is that although the yield potential of climbing beans is generally considered to be higher than bush type beans, the farmers managing the Milpas place priority on the management of the maize and thus obtain extremely low yields from climbing beans (50 to 300 Kg per ha). The Instituto de Ciencia y Tecnologia Agricolas (ICTA), the national agriculture research program in Guatemala, had collected and characterized over 600 accessions of climbing bean landraces but had invested limited effort in genetic improvement due to limited resources. The Legume Innovation Lab, recognizing the incredible potential value of this germplasm collection, supported a research effort led by North Dakota State University to genetically characterize the climbing bean collections from Guatemala along with other accessions in a Mesoamerican Diversity Panel (a selection of accessions from races Mesoamerica and Durango-Jalisco).

Following genomic analyses of the Guatemalan germplasm collections utilizing 45,128 SNPs to characterize genetic diversity, it was determined that Guatemalan climbing beans are a unique genetic group (established as "Race Guatemala") that can be genetically differentiated from other races/subgroups within the Middle American gene pool (see Figure 1) and that intra-race diversity is similar to other races within the gene pool. Genome-Wide Association Studies (GWAS) identified genomic regions that are associated with several traits of economic importance (e.g., seed shape, adaptation to high altitude, disease resistance, etc.).

ICTA-Guatemala is the only breeding program in the world focusing on gene discovery and the genetic improvement of Middle-America climbing beans. This program is a complement to CIAT's Andean climbing bean breeding program. Genes of initial interest and future exploration by ICTA include novel genes for resistances to *Ascochyta* Blight, Rust and Anthracnose, adaptation to low temperatures/high altitudes, assimilate partitioning, seed yield potential, and for pod distribution within a plant. These are traits that have already been observed and molecular markers identified within this germplasm pool (Table 3, page 19).

The creation of a pipeline of elite climbing bean breeding lines with novel genes by ICTA-Guatemala will be a highly valuable genetic resource for common bean breeding programs around the world, especially in highland regions of Africa and temperate bean production areas of North America.

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

University of California Riverside scientists Drs. Phil Roberts and Tim Close in partnership with collaborators at INERA (Burkina Faso), ISRA (Senegal) and SARI (Ghana) utilized genomics and modern breeding to improve cowpea yield in West Africa by targeting insect resistance. This Legume Innovation Lab project focused on insects attacking early (aphids), mid-flowering and pod set (flower thrips) and latter pod filling (pod-sucking bugs) cowpea development stages, and achieved the following major genetic advances.

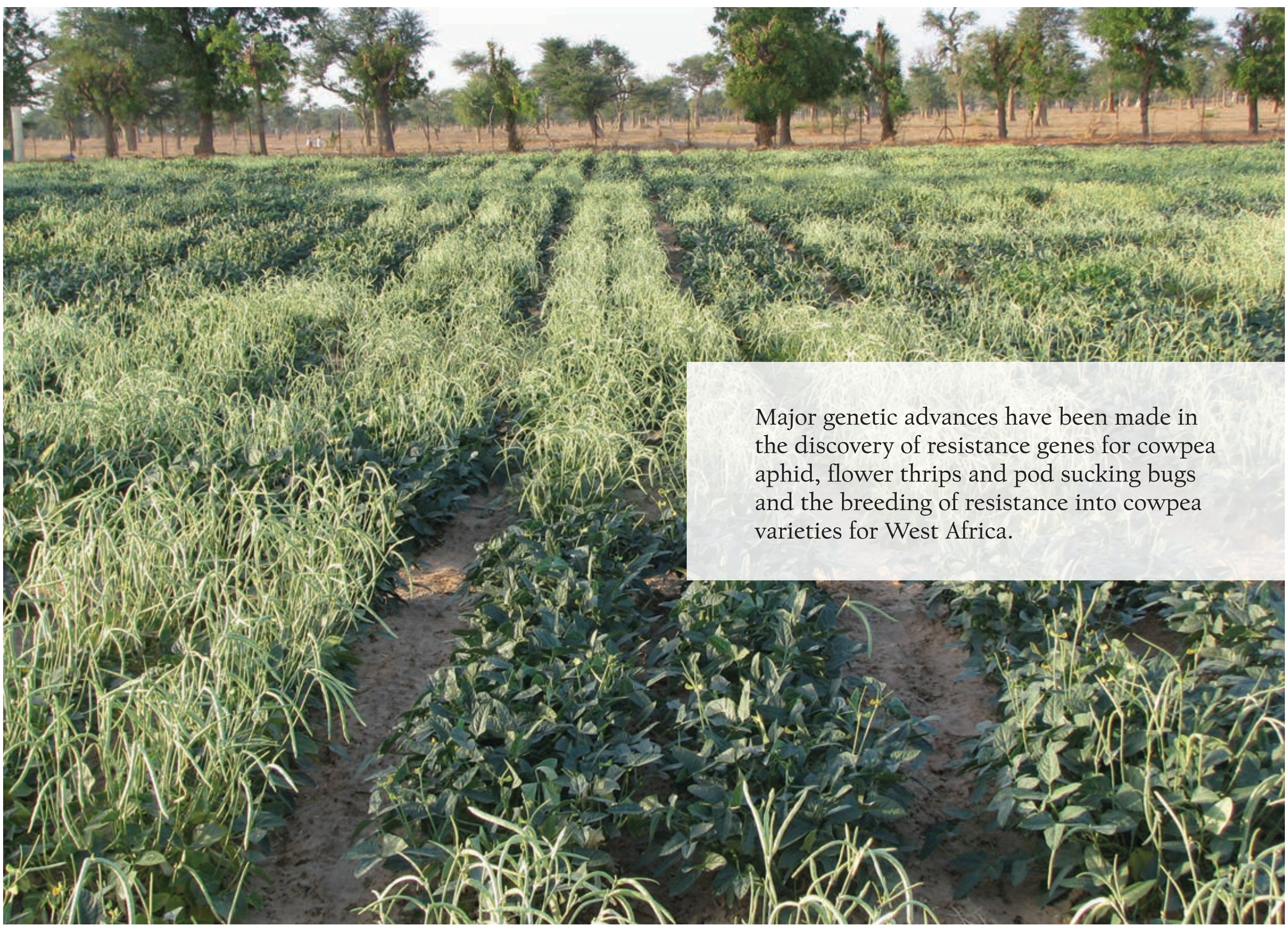
| Cowpea Aphid Resistance |

Through phenotyping and genotyping of cowpea populations segregating for insect resistance, aphid (*Aphis craccivora*) resistance was identified in two cowpea lines, IT97K-556-6 and SARC-1-57-2 (from Ghana) (Table 1, page 11). Genetic mapping of the aphid resistance in IT97K-556-6 at UCR revealed two QTLs on cowpea linkage groups LG1 and LG7. Through recurrent backcrossing, the two aphid resistance QTLs were introgressed into the California blackeye pea lines CB46 and CB50. SNP markers for the QTLs confirmed the presence of the aphid resistance genes. These best yielding lines for the aphid resistant CB46 and CB50 are being evaluated under field conditions for possible future release in the US.

Using SSR marker analysis for the SARC-1-57-2 resistance together with genomewide SNP markers, the major aphid resistance locus was mapped to cowpea LG 10 utilizing two SNP-genotyped biparental RIL populations. This confirmed that the SARC-157-2 aphid resistance gene is distinct from the resistance genes in IT97K-556-6 on LG7 and LG1.

| Flower thrips resistance |

Tolerance genes for flower thrips (*Megalurothrips sjostedti*) were SNP-mapped at loci *Cft-1* and *Cft-2* in a line resulting from the cross of Sanzi (thrips tolerant) x Vita 7. Thrips resistance was also found in families resulting from crosses of Sanzi x 58-77 and in large seeded cowpea varieties (ISRA-3178 and ISRA-3217 in Senegal (Table 1, page 11). INERA- Burkina Faso scientists also confirmed flower thrips resistance in genotypes SANZI, TVx3236 and TVu1509. Crosses have been made using these lines as parents with resulting populations being genotyped and phenotyped for genetic analysis and resistance marker discovery.



Major genetic advances have been made in the discovery of resistance genes for cowpea aphid, flower thrips and pod sucking bugs and the breeding of resistance into cowpea varieties for West Africa.

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 (Table 1, page 11). Results indicate multi-genetic gene action for resistance to pod-sucking bugs in cowpea.

As a result of this foundational genetic research involving novel resistance trait and gene discovery conducted by the LIL UCR-led research team, four pre-release advanced cowpea lines are being evaluated for yield and insect resistances by INERA-Burkina Faso in multi-locational trails with release petitions scheduled for 2019.

Smallholder farmers in Uganda and Zambia can look forward to planting improved common bean varieties with enhanced N-fixation under low fertility soil conditions and robust resistance to foliar diseases limiting yield.

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

Since bean production by smallholder farmers in Uganda and Zambia is primarily constrained by plant diseases and abiotic stresses, this project led by Dr. James Kelly at Michigan State University in collaboration with scientists at NaCCRI-Uganda and ZARI-Zambia sought: 1) to characterize pathogenic and genetic variability isolates of foliar pathogens collected in these two countries and identify sources of resistance to angular leaf spot, anthracnose, common bacterial blight, bean common mosaic virus and bean rust; 2) to identify QTLs for drought tolerance, disease resistance, biological nitrogen fixation for use in Marker Assisted Selection to improve germplasm; and 3) to develop improved varieties which pyramid genes for foliar diseases, drought and improved BNF.

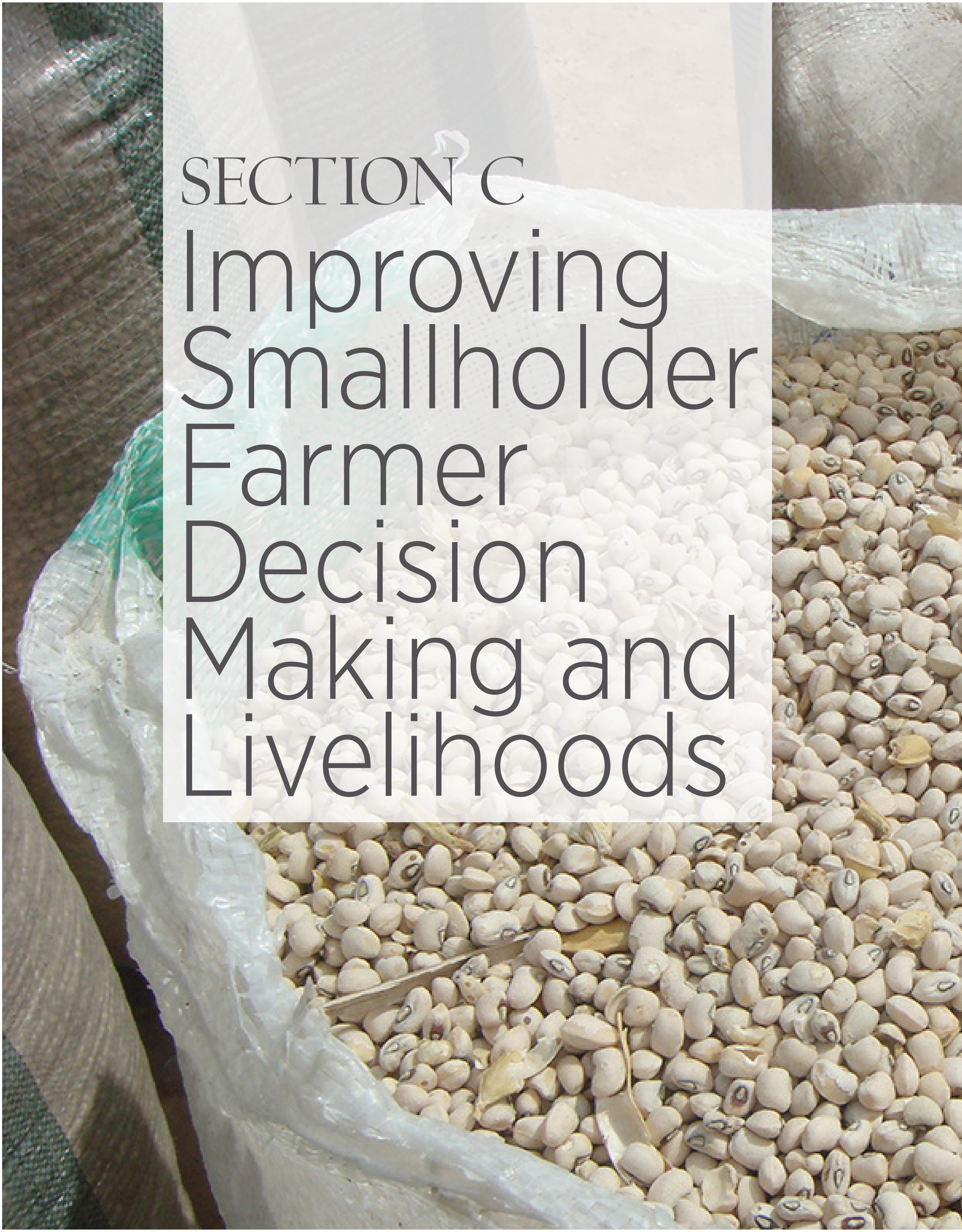
The following seminal technical genetic research advances were made during the Legume Innovation Lab phase (FY2013-17) due to access to modern molecular genetic tools.

- The genomic regions controlling anthracnose resistance and enhanced biological nitrogen fixation plus the candidate genes underlying these functions were pinpointed on the bean genome using SNP markers and RNA sequencing.
- Resistance genes for rust, CBB, BCMV, *Sclerotium* root rot and drought were identified and introgressed into Uganda bean lines of Andean market classes.
- Promising drought tolerant lines (Table 1, page 11) were identified and included in trials for possible new varietal release in Uganda by end of 2017.
- The modes of inheritance of resistance genes for rust, CBB, BCMV and BCMNV were determined for selected Ugandan Andean genotypes

As a result of this strategic genetic research, smallholder farmers in Uganda and Zambia can look forward to planting improved varieties of Andean market class beans with enhanced N-fixation under low fertility soil conditions and robust resistance to those foliar diseases that have been limiting yield and thus ability to provide for household food and nutritional security needs.

SECTION C

Improving Smallholder Farmer Decision Making and Livelihoods



Innovation Platforms – A Model to Improve Social Learning and Site-Specific Decision Making by Smallholder Farmers to Increase Bean Productivity and Sustainable Improvements in Soil Fertility {C1}

Poor soil fertility is a primary factor limiting common bean yields on smallholder farmers in most Feed the Future focus countries in Sub-Saharan Africa and Latin America. Improving smallholder farmer decision making regarding the integrated management of soils, including the use of inputs, to profitably and sustainably achieve higher yields is a challenge facing agriculture development professionals.

> Innovation platforms provide a space for diverse actors with shared vested interests in a problem to come together to collectively diagnose the constraint, consider and test possible alternative solutions, learn from one another, and to take action.

A Feed the Future Legume Innovation Lab project in Uganda, led by Dr. Robert Mazur and fellow collaborators at Iowa State University (ISU), Makerere University and the National Agriculture Research Laboratories-Uganda (NARL) in Uganda used "innovation platforms" as an approach to interact with smallholder farmers and promote better soil and agronomic management decision making for their specific agro-ecological and socio-economic context.

The project was based on two premises: (1) sustainable intensification of agriculture production requires improved soil fertility management in which legumes are an integral part of the cropping systems; and (2) effectively addressing soil-related constraints will be based on enhancing smallholder farmers' capabilities to diagnose and find solutions to important yield constraints, as well as helping to remove barriers to increased access to various types of soil amendments.

Innovation platforms (IP) were considered to be an attractive approach to overcome the soil fertility problem. IPs provide a space for diverse actors with shared vested interests in the problem (such as smallholder farmers, researchers, agriculture extension specialists, private sector agriculture service providers, vendors, etc.) to come together to collectively diagnose a problem or constraint, consider and test possible alternative solutions, learn from one another, and to take action to overcome the constraint.

During the recent Legume Innovation Lab phase (2013-2017), a multi-stakeholder 'bean' Innovation Platform was established in Masaka and Rakai Districts in Central Uganda which has significantly grown in size (1000 plus members), capacity (10 value-chain member organizations), enthusiasm and certainly potential to effect change.

Critical steps taken by the ISU-led team that contributed to the apparent success of Ugandan Bean IP include:

1) Conducted in-depth interviews with a representative cross-section of 300 farming households to gain insights on land ownership, field selection and land preparation, crop and variety selection, planting methods and spacing, input use, intercropping and rotation patterns, gender-based division of labor, problem identification and management practices, market sales, storage practices, food consumption

patterns, and uses of income earned through farming and other activities, connections in social and economic networks, diet and food security.

2) Established community-based field trials, 1 acre in size, with approximately 30 neighboring farmers engaged at each site. Local farmers, extension workers, and scientists were involved in the selection of the sites based upon soil data analyses, and cropping management and soil amendment histories of the site. The sites for the field trails were both provided and managed by IP member farmers. A participatory approach was used to decide soil amendments (poultry manure, compost, inorganic fertilizer, lime, etc.) and management practices to be tested at each site and in monitoring and evaluation of responses during the growing season.

3) Facilitated formal learning at each site by farmers with stakeholders. Learning was achieved at all stages during the year, including pre-season planning, growing season when trials were in the field, organized farmer field days, assessments of treatment data results, and when planning future follow-up experimentation during end-of-season IP meetings.

4) Follow up with informal social learning. Social learning occurs when IP member farmers share what they have learned with other women and men in their own communities. To foster this social learning, communication researchers worked with IP farmers and other project researchers to develop and field test a SAWBO video animation in Luganda and English summarizing key research-based farmer-validated bean production recommendations for Uganda. A companion print version was also created for those who lack access to smartphones or computers. Similar SAWBO videos and a video on jerry-can storage of bean seed were also developed in Portuguese for use in Mozambique.

> Site-specific management practices must be implemented to achieve higher bean productivity and profitability and long-term improvements in soil fertility.

Over the course of the project, more than 20 community-based field trials were conducted during each of five growing seasons. These field trials of crop performance and yield responses validated solutions to initial analyses of soil physical and chemical properties for each site and enabled farmers to develop site-specific management strategies that provide positive results for smallholder bean farmers.

In 2017, the final year of the project, the LIL research team sought to document IP farmers' actions to invest and adopt new management practices. Behavior change and technology adoption are the most rigorous tests of the effectiveness of the IP approach along with positive farmer experience with the use of technology. To this end, interviews and focus groups were conducted with farmers and leaders of multi-stakeholder innovation platforms. The findings provided the basis for the

formulation of recommendations for training and continued technical support to increase bean crop productivity, marketing and sustainable soil fertility improvement.

Selected key recommendations to increase bean yields and improve soil fertility in Central Uganda included:

- Plant quality seed of genetically improved locally-adapted bean varieties with multiple disease resistances
- Increase stand density to 20 plants/m2 with 50 cm spacing between rows
- Utilize agricultural limestone at 1 to 2 Mt/ha to adjust soil pH, reduce Al toxicity and increase availability of Ca, Mg and K (Note - the low yield benefit of liming in certain soils may not make this profitable.)
- Apply di-ammonium phosphate (DAP), urea and chicken manure according to soil type
    - Red soil - 30 kg DAP, 1.2 kg urea, 1000 kg chicken manure per acre
    - Gravelly soil - 30 kg DAP, 1.5 kg urea, 1000 kg chicken manure per acre
    - Black soil - 15 kg DAP, 0.75 kg urea, 1000 kg chicken manure per acre
- Band application of fertilizers in the row for increased uptake efficiency
- Weed at three critical stages of bean crop development (approximately 2, 5, and 7 weeks after emergence)

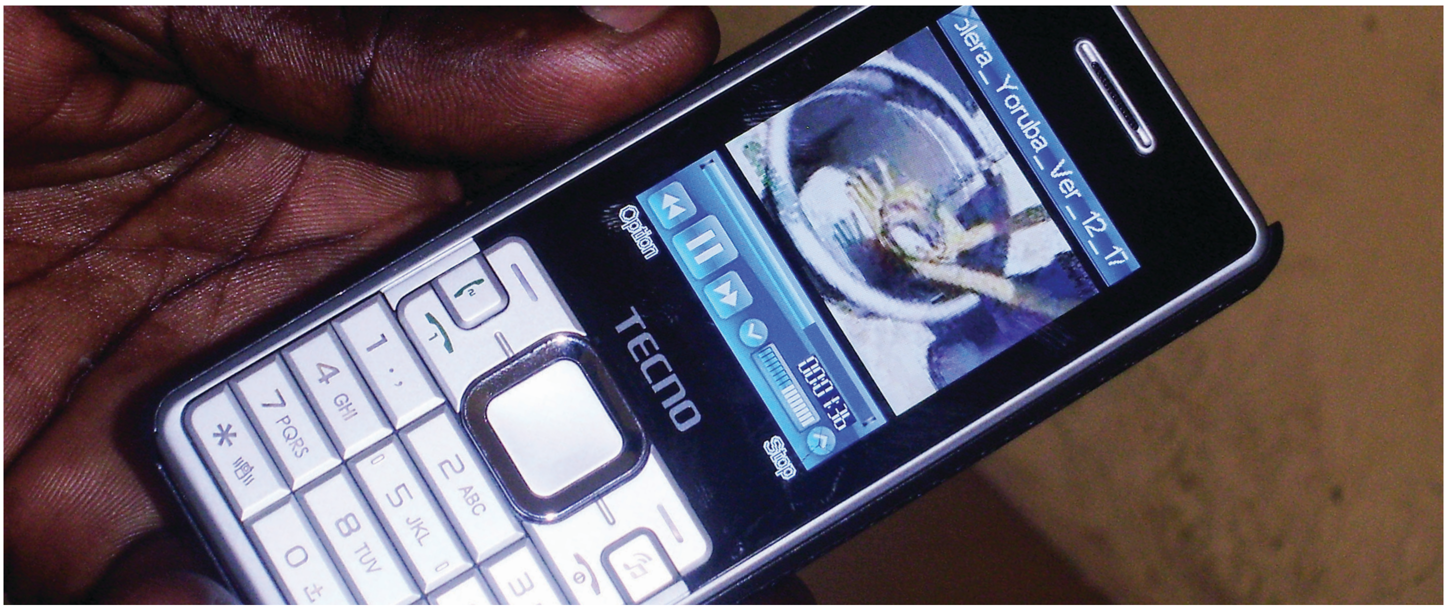
Important findings from the Legume Innovation Lab project were that recommended integrated management practices are not equally effective in all locations and that site specific management practices must be implemented to achieve higher bean productivity and profitability and long-term improvements in soil fertility. The combination of community level soil analyses for both chemical and physical properties and soil mapping in combination with local field trials is conducive to the identification of effective site-specific management options for farmers. Costs of production analyses are also necessary to determine if a technology provides a profitable return on investment in a particular locale.

LIL project scientists conclude that the Innovation Platform approach along with proven educational and communication tools (e.g., SAWBO animations, printed guides for low education learners, and radio messages) provide a mechanism to effectively scale up and achieve adoption of profitable bean yield and soil fertility enhancing technologies.

SAWBO–Using Modern Cell-phone Based Communication Platforms to Bring Technology to Farmers {C2}

How do low literate smallholder farmers living in countless rural communities throughout developing countries in Sub-Saharan Africa, Latin America and Asia learn about new technologies resulting from agriculture research that could improve their productivity and livelihoods? This is the question facing development professionals around the world. The reality is that many technologies including new varieties, improved agronomic practices, integrated pest management approaches, soil fertility management practices, post-harvest storage technologies, etc. have been developed by agricultural scientists over the years but are unfortunately unknown or unavailable to smallholder harmers and thus not adopted.

Scientific Animations Without Borders (SAWBO) was developed by LIL scientists Drs. Barry Pittendrigh and Julia Bello Bravo, Michigan State University faculty, for that purpose. They transform expert knowledge into interesting and easy to understand educational animations that can be readily translated into any language depending upon the target population and country. To achieve its impact goal, SAWBO animations can be accessed and downloaded free of charge from their webpage (www.sawbo-animations.org) or using their App (http://goo.gl/vz3vbA) for educational purposes by either individuals or groups.



A revolution in communications has occurred however within the past decade. Both the urban and rural poor have gone from being completely isolated from the world to ownership of, or access to, smart phones that can enable them to communicate and instantaneously receive information on any topic they desire. Moreover, they can receive and view educational content and videos as attachments to texts, via Bluetooth®, or through a Wi-Fi connection to the Internet. This technology leap is providing a platform for getting valuable information out to large numbers of rural households with little cost and effort so that the disadvantaged can also benefit from technological advances from agriculture research programs such as the Dry Grain Pulses CRSP and the FTF Legume Innovation Lab (LIL).

With LIL support, SAWBO animations have been developed on such topics as:

- Biocontrol of Legume Pod Borer (*Maruca vitrata*)
- Improved Bean Production (including specific videos for Mozambique and Uganda)
- Natural Insecticide from Neem Seeds
- Solar Treating of Cowpea Seeds
- An assessment of learning gains from educational animated videos
- An assessment of impact on adoption of the technique given in the educational animated videos.

These plus other topical animations have been tested in numerous African countries to assess their effectiveness. Dialectically localized animated educational SAWBO videos have been shown to be as effective as traditional extension presentations in achieving learning gains of knowledge on agricultural and health related topics. However, the video animations were found to lead to more detailed knowledge retention. Preference for the video education approach has been widely expressed by African viewers and a desire to digitally share SAWBO content with others in their community through the use of mobile phones. A two-year post-animation intervention showed high levels of adoption of the technique shown in the animation.

A priority application of SAWBO is to use the existing and new animations to scale up the sustainable biological-based IPM technologies (parasitoids, neem oil emulsions, MaviMNPV virus, *B. passiana* fungus, pheromones, insect resistant varieties) for control of insect pests in cowpea production areas throughout West Africa. SAWBO has also developed approaches that will allow for easy pass-off to and use by organizations that can scale this educational content. There also exists future opportunities to study the most effective scaling strategies of such education content. By understanding the available technological IPM options, LIL believes that low literate smallholder farmers can make more informed decisions and choose effective biocontrol solutions that best fit their situation.

Dialectically localized animated educational SAWBO videos have been shown to be as effective as traditional extension presentations in achieving learning gains of knowledge on agricultural and health related topics.

Participatory Soil Mapping of Smallholder Farm Landscapes Integrates Local Knowledge for Increased Soil Fertility and Cropping System Sustainability {C3}

Soils managed by smallholder farmers in most Feed the Future countries have low fertility which limits crop yields. Many of these soils are highly degraded due to continuous cropping over many decades without the use of soil conservation practices to retain organic matter and promote soil health (a diverse biota in the soil). Additionally, inputs have not been available to sustainably maintain soil pH levels and mineral nutrient concentrations. The challenges of improving soil fertility in cropping systems is largely due to the lack of analytical data on the chemical and physical properties of soils in most African countries and the high degree of variability in soil type and fertility from one field to another or from one farm to another. Quality soil analytical services are not readily available and are costly to smallholder resource poor farmers in developing countries. Moreover, large variability in soils within a smallholder production landscape prevents agriculture extension service technicians from providing soil fertilization and management practices that will enhance crop yields and soil quality in both the short and long terms.

In recognition of the importance of addressing low soil fertility to improve grain legume yield, the Dry Grain Pulses CRSP and the FTF Legume Innovation Lab supported a multi-disciplinary research project lead by Dr. Robert Mazur, Iowa State University (ISU), in collaboration with scientists at the University of Hawai'i at Mānoa, Makerere University and the National Agricultural Research Laboratories in Uganda and the Institute of Agricultural Research in Mozambique (IIAM). The project focused on improving farmer decision making to achieve sustainable soil fertility management and increased bean productivity by smallholder farmers in these countries. Drs. Lee Burras and Bradley Miller, ISU, provided the intellectual leadership on soil mapping.

The underlying premise of the soil mapping is that an integrated management approach in which farmers choose among alternative soil and crop management practices in accord with available resources can lead to incremental improvements in bean and cropping system productivity and sustainability.

Influencing farmer decision making to achieve long-term productivity and sustainability goals is, however, a formidable challenge. Resource-poor and food insecure farmers are inclined to make cropping system management decisions based upon the amelioration of risk and a desire to obtain short term returns in food production and/or profit generation.

A key objective of this research study was to gain insights into smallholder farmers' motivations, knowledge and practices regarding soil management with the goal of developing a model(s) for improved integrated crop and soil fertility management decision making.

> The participation by local farmers in mapping and diagnosing soil-related problems contributed to better integration of indigenous knowledge with scientific knowledge, mutual learning and an appreciation by both farmers and scientists regarding the complexities of land usage and soil management.

LIL scientists learned early in the research process that low literate smallholder farmers have their own methods for classifying soils and possessed quite a bit of indigenous knowledge on soil management predominantly based on experience.

An innovative community-based participatory approach taken by this project was to (1) develop a simple soil classification system based upon observable characteristics and local soil names, (2) understand local soil-landscape relationships to these soils, (3) measure the physical and chemical properties of the soils, and (4) produce a set of visual maps that aid farmers in making crop and soil management decisions.

The creation of community-level landscape soil maps in a participatory manner with local farmers was found to be highly valuable. The participation by local farmers in mapping and diagnosing soil-related problems contributed to better integration of indigenous knowledge with scientific knowledge, mutual learning and an appreciation by both farmers and scientists regarding the complexities of land usage and soil management. The process also engendered trust, interest, changes in mindsets regarding the value of soils, and a commitment to collective community action to improve soil quality and usage for shared benefits. Certainly soil conservation practices including soil erosion management and allocations of land for alternative uses requires a collective effort by both farmers and community leaders.

ISU scientists Drs. Bradley Miller and Lee Burras provided leadership in the development and testing of three types of soil maps with farmers in the villages of Kiwanyizi and Kaganda, Masaka District, in Uganda. These soil maps sought to inform and facilitate a discussion with farmers in the community regarding land usage and management.

Elevation Map – This map (Figure 2) provided information on different soil types along hillslopes (catenas) within a landscape where many smallholder farms are located. Elevation data from the Shuttle Radar Topography Mission (SRTM) were used to develop a high resolution base map of slope gradients. Fieldwork with local farmers provided data on soil types and their GPS coordinates within the landscape. This map enabled farmers to understand the variations in soil type within a landscape, plus to relate soil position and soil analysis information (i.e., pH, texture).

Satellite Image Map – Soil type information across the landscape was superimposed upon a satellite Image Map (Figure 3). This map enabled farmers to visually locate their own homesteads and field sites according to landscape features (roads, homesteads, forested areas, etc.) and to associate current landscape usage to soil types. This is important because farmers typically prioritize using fields having soils with highest productive potential.

Soil-Landscape Block Map – The block map presented in Figure 4 was found to be effective in communicating soil-landscape relationship concepts to farmers. Farmers could appreciate the repeating patterns of soil types within a sloped area (catena) and the importance of soil conservation practices to minimize erosion. This map also facilitated discussion of where to plant specific crops according to their adaptive characteristics to soil conditions. For example, pigeon pea grows well in red soils with moderately low pH, while common bean with a shallower root system and a high pH requirement is better adapted to the black or low alluvial soils. In addition, farmers can consider long-term management options to

FIGURE 2. Elevation Map

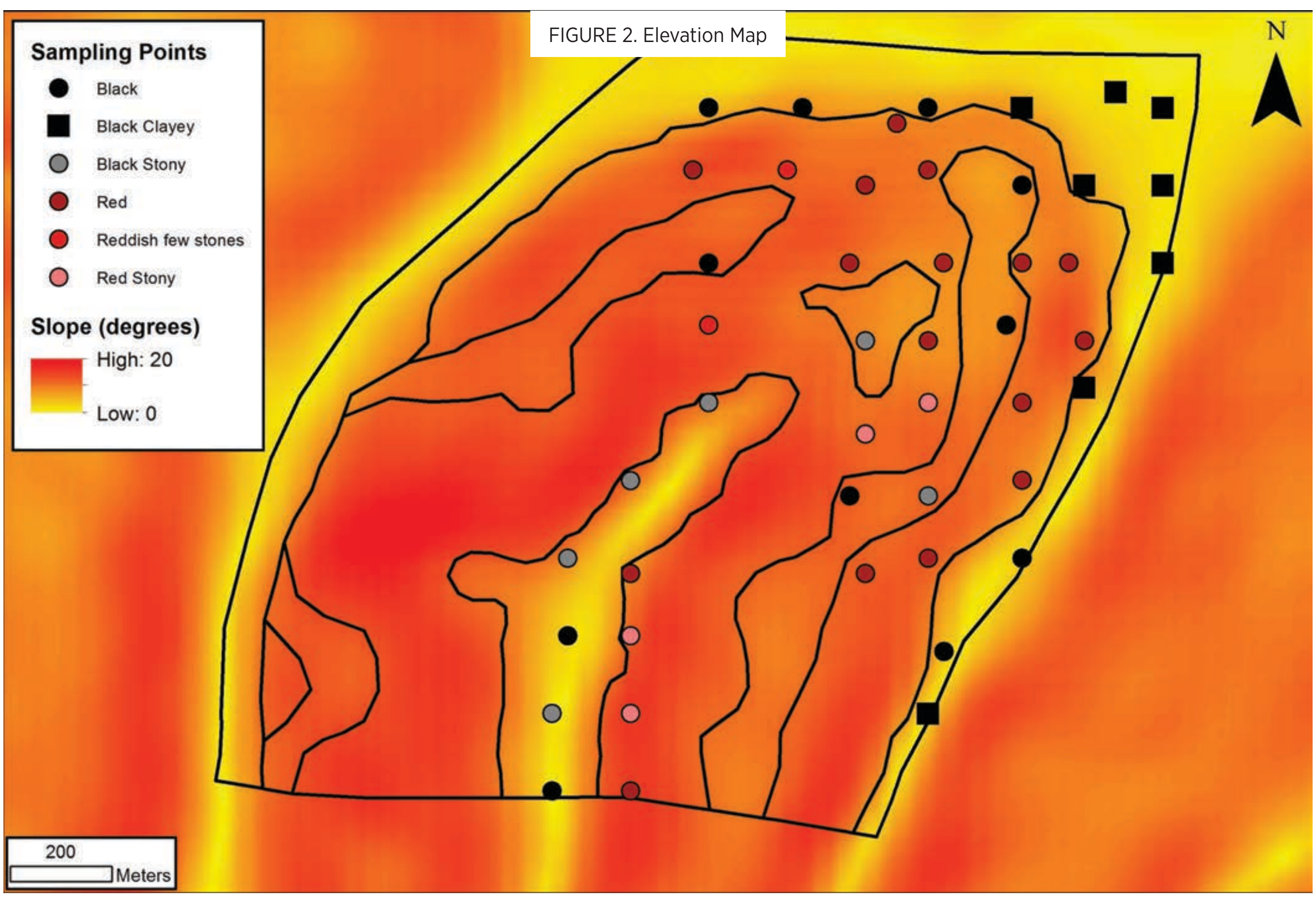


FIGURE 3. Satellite Image Map

improve soil fertility of each soil type and the importance of coordinating management efforts with other smallholder farmers living on the same hillslope.

Parallel LIL research activities led by Drs. Andrew Lenssen, ISU, and Russell Yost, U. Hawaii-Mānoa, involved field trials conducted in Uganda and Mozambique, respectively, to determine integrated management solutions to soil fertility and bean productivity constraints on the predominant soil types in key bean producing regions in these countries. The results validated the need for and use of soil analytical data and for development of soil management guides (simple decision support tools). These guides include:

- Soil type characteristics and suitability to support the production of specific crops
- Risks of soil erosion, soil organic matter loss and degradation in soil health
- Recommendations for chemical (di-ammonium phosphate, urea, potash, complete fertilizers, etc.) and organic (chicken manure, compost) fertilizer and lime applications

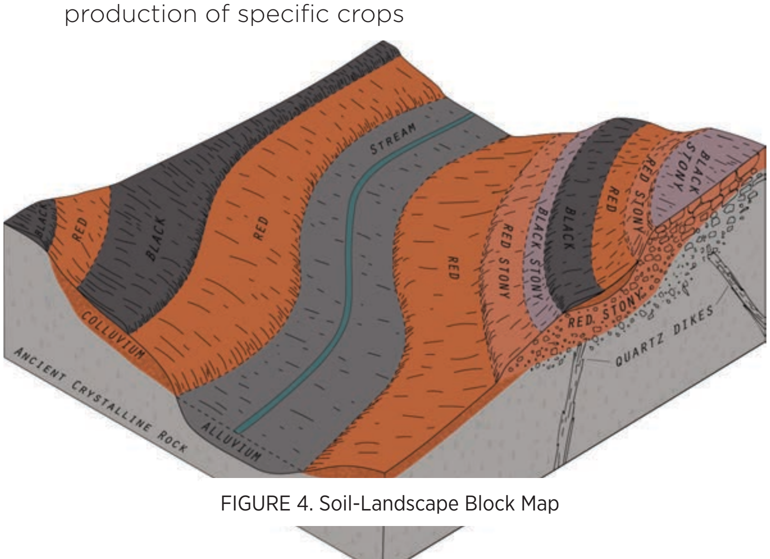


FIGURE 4. Soil-Landscape Block Map

The Legume Innovation Lab believes that this innovative approach is a game-changer to sustainable soil fertility management in smallholder farm contexts and can be readily scaled up. The participatory development of soil maps and the use of soil fertility management guides were well received by farmers and require minimal initial investment. It was estimated that less than 50 hours of total time by a soil scientist is necessary to complete the entire process of engaging a community of farmers, soil sampling, soil mapping, preparation of block diagrams and management guides, and follow up with farmers. The resulting soil maps were the first for that region in Uganda providing sufficient spatial detail to be meaningful for smallholder farmers' management decisions.

The effectiveness of this approach in changing farmer behavior is believed to be high due to the fact that this approach builds upon local farmer knowledge of soils, is participatory, and provides farmers with easy to understand tools for site specific management of their local farm settings.

Quality Seed – The Most Important Input Investment for a Bean and Cowpea Farmer {C4}

For smallholder farmers to benefit from USAID investments in bean and cowpea breeding, they need to have access to seed of the improved varieties. Unfortunately the lack of availability of quality seed of improved varieties at an affordable price prevents resource-poor famers in many countries from experiencing the yield boosts and resistances to diseases and stress that are afforded by improved genetics. It is because of constraints to seed access that the adoption of improved grain legume varieties is so low in many developing countries of Sub-Saharan Africa and Latin America.

> Initiatives that promote the adoption of improved varieties without addressing long-term farmer access to quality seed will likely result in poor farmer experience and thus not achieve the intended adoption goals.

Since enhancing grain legume productivity is a priority strategic objective, the Dry Grain Pulses CRSP and the FTF Legume Innovation Lab have focused efforts on understanding seed access constraints and implementing seed dissemination projects to gain field experience with grain legume seed systems. Through the design of seed multiplication and distribution initiatives, LIL scientists were able to test novel seed system models, understand factors that add cost to seed, and gain insights into factors that limit quality seed of improved bean and cowpea varieties from reaching farmers in geographically and economically marginalized areas.

Lessons learned from LIL studies and project experiences include:

A. Smallholder farmers are willing to pay a premium for quality bean seed

Studies led by Dr. Mywish Maredia, Michigan State University, conclusively showed that the quality of seed planted by resource poor farmers does make a difference. When bean grain, purchased from local markets, was planted along-side "Certified Seed" in field demonstration trials in Nicaragua, the high quality seed resulted in higher yields. The important lesson is that initiatives that promote the adoption of improved varieties without addressing long-term farmer access to quality seed will likely result in poor farmer experience and thus not achieve the intended adoption goals.

It was also learned that farmers are able to perceive quality differences in seed and therefore are willing to pay a premium for quality seed if they can trust the source. Poor seed quality is evidenced by low field germination, vigor and lack of uniformity in emergence. Through bidding experiments, it was discovered that 30% of smallholder farmers were even willing to pay a price above that of certified seed because they recognized the clear potential return from an investment in quality seed. Studies in many developing countries, however, indicate that smallholder farmer purchases of quality seed are extremely low possibly due to a lack of trust in certified or quality declared seed (QDS) or a lack of availability of quality seed in local markets. The positive finding is that market demand exists for quality seed which should be an incentive for the establishment of small seed enterprises that sell verifiable high quality bean and cowpea seed at an affordable price to farmers in their communities. Innovations though are needed to develop economical means to multiply, handle, condition and package seed for sale to smallholder farmers.

B. Quality seed can be produced through community-based seed multiplication systems

As follow up to a Legume Innovation Lab Associate Award, "Bean Seed Dissemination in Honduras, Guatemala, Nicaragua, Honduras and Haiti", Dr. Mywish Maredia and associates conducted case studies of community-based seed production models in these countries.

MASFRIJOL- Guatemala

OBJECTIVE: To enhance the food and nutritional security of Mayan households in the Western highlands of Guatemala through increased access to and consumption of beans.

ACHIEVEMENTS:

- 35,000 households received 5 lbs of quality seed of an improved black bean variety (*Hunapú*, *Altense*, *ICTA Ligero*) adapted to the agro-ecologies of the highland region
- 80 Community Seed Depots were established and are producing Quality Declared Seed (QDS) to sell to smallholder farmers in rural highland communities
- Quality Declared Seed of improved black bean varieties are sold at 20 to 100% above bean grain prices making seed multiplication a profitable endeavor for Community Seed Depot farmers.
- 23,000 participated in nutrition education classes and 5,000 in bean cooking classes
- Farmers attain bean yields of up to 2 MT per ha from planting quality seed of the improved varieties.

Assessment of "community seed banks", a model promoted by the government in Nicaragua to increase the availability of bean seed in local communities, revealed that leader farmers in rural communities could produce "Apta" seed (multiplied from Registered Seed) which meets most seed quality standards (germination, vigor, uniformity, moisture content). Reducing seed moisture content to <15%, important for extending seed storage life and vigor, was the greatest challenge for seed multipliers due to an inability to control humidity without technologies to effectively dry and store the seed.

The sustainability of the community seed bank (CSB) model was however found to be poor as evidenced by two thirds of the CSBs closing within one year after technical assistance ended. The justification given by farmers for not continuing their seed multiplication enterprises was because of the high risk of crop loss due to drought. Surprisingly, the profitability of the enterprise was not the primary reason provided. This experience demonstrates that seed multiplication is similar to any other farming endeavor; one must have confidence that a good return can be obtained from investments in inputs to produce a seed crop. Seed multiplication requires more inputs that grain production due to the need to control diseases and pests. Irrigation therefore is a prerequisite for quality common bean seed production in drought prone areas, regardless of scale.

In Haiti, it was discovered that farmers were not able to identify the names of the bean varieties purchased and planted on their farmers. This presents a formidable challenge to the adoption of improved varieties. Without knowing the identity of varieties from which they have had a positive experience (high yield, good plant health, preferred cooking attributes), farmers cannot seek out and purchase the same variety in subsequent seasons. Educating farmers on the identity of improved varieties and their characteristics is imperative for creating demand, achieving adoption and developing sustainable seed systems.

C. MASFRIJOL links technical assistance and nutrition education to jump-start community-based bean seed production in Guatemalan highlands.

MASFRIJOL, an associate award to the FTF Legume Innovation Lab, provided training and technical assistance to smallholder leader farmers in rural highland communities in Guatemala to enable them to profitably produce, condition, store and market quality common bean seed to other farmers in their community. Along with an initial start-up technology package containing registered seed of an improved bean variety, pesticides and fertilizer, farmers also received regular visits from extension specialists to verify that the bean fields were well managed and disease free, prerequisites for the production of quality seed.

To generate demand for seed of improved bean varieties and increase household consumption of beans, cross training was provided to both government agriculture extension and health/nutrition specialists working in communities. These specialists received classes on both seed production and handling practices as well as on human nutrition and the importance of nutrient-rich foods such as beans in the diets of the indigenous populations. In this manner, the two groups of specialists became joint advocates for beans as a nutritious staple food and cash crop among both women and men in the communities.

The results of this effort have been close to incredible. Most bean farmers who purchased and planted the seed have achieved 50%, 100% or even >200% increases in bean yield over past experience. This success is being attributed to two factors. First, the farmers experienced for the first time the value of planting high quality seed; increased yields resulting from higher plant populations due to high seed germination rates. The second contributing factor was that farmers planted improved varieties with a determinant architecture. By planting these varieties in monoculture, the farmers were able to control diseases and pests more easily and achieved significantly higher bean yields than traditional landraces planted in the milpa system (beans in association with maize).

The lessons learned from the MASFRIJOL experience is that bean seed multiplication affords profit generating opportunities for entrepreneurial smallholder farmers in marginalized communities plus contributes to the seed security of the community. Secondly, education of farmers on the nutritional value of beans and the return on investment to planting quality seed of improved varieties, ultimately contributes to increased farmer commitment to growing beans for better household nutritional security and livelihoods.

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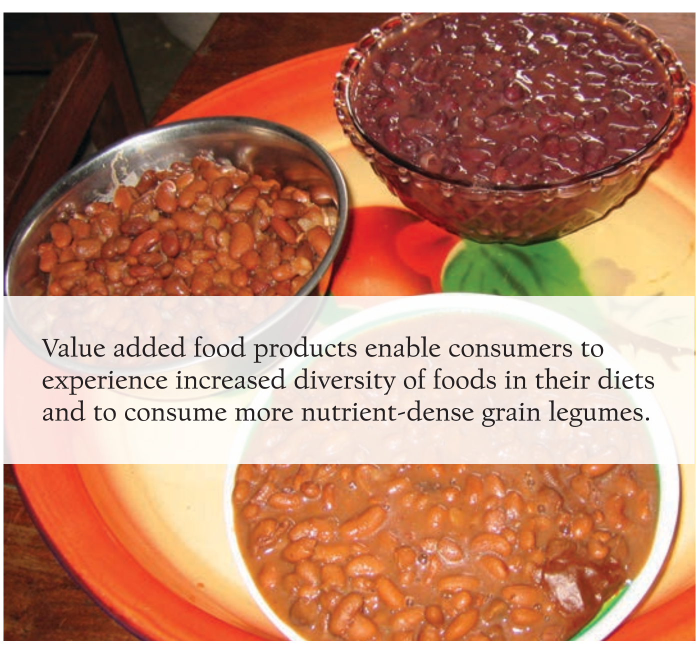
Consumer Preferences and Markets Matter to Smallholder Farmers {C5}

Market demand for beans and cowpeas provides a sustainable pull for farm level production when demand and supply are matched in quantity, quality and timing. The Dry Grain Pulse CRSP and the Legume Innovation Lab research agenda addressed constraints and knowledge gaps in both the supply and demand sides of the grain legume value chain continuum. An understanding of food preferences by both rural and urban consumers and determinants of dietary decision making are major demand side knowledge gaps in Eastern and Southern Africa. Research by the DGP CRSP and LIL sought to elucidate factors that influence grain legume consumption and utilization by consumers in order to develop varieties with desired traits, to identify business opportunities for value addition, and to formulate recommendations for policy makers to incentivize grain legume value chains.

Dr. Vincent Amanor-Boadu, Kansas State University (KSU), in collaboration with scientists in Zambia, Tanzania and Malawi, identified grain legume grain size, color, gravy quality and cooking time as key determinants of consumer preference. LIL sponsored breeders participating in the research developed a strategy for crop improvement entitled "Breeding for Supply Chain Performance." This strategy uses consumer preference information to set varietal development objectives, ensuring that future releases of varieties contribute to the financial performance of all the actors in the value chain.



Value added food products enable consumers to experience increased diversity of foods in their diets and to consume more nutrient-dense grain legumes.

Earlier research in Zambia under the DGP CRSP demonstrated that cowpea and common bean value chains are quite distinct. Cowpea farmers are highly reliant on informal trading and barter for sale of grain with their neighbors, whereas common bean farmers tended to sell to private traders, especially when distance to markets is relatively low, grain prices are high, and farmers have large volumes of grain to sell. When markets are distant, households tend to focus on food security and sell less to private traders. Private traders assume the role of accumulating bulk quantities of grain so as to gain market leverage in urban areas and with large-scale traders and processors. They also play a key interfacing role by informing farmers of grain prices and fluctuations in market demand for quantity and quality.

The challenge facing the bean sector in Eastern/Southern Africa (Tanzania, Malawi, Zambia) is that beans are not the principle food in diets, as revealed by a LIL multi-country consumer survey. Dr. Amanor-Boadu states that "beans do not sit in the center of the plate in these countries, but rather on the sidelines as a relish or small portion." Out of the five key consumption groups, cereals ranked as the number one food consumed, while grain legumes were only fifth in importance in Zambia and Malawi, yet third in importance in Tanzania. The study also revealed that consumer preference for culinary traits varied significantly from one country to another. For example, Malawian consumers preferred red mottled beans because of gravy quality, while Njano and Kabulangeti beans were preferred in Tanzania and Zambia, respectively. The take-home lesson is that breeding objectives need to be specific for individual countries and markets, as well as demographic groups.

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LIL consumer research on cowpeas in Senegal and Zambia, two highly distinct populations, showed that green pods, green shelled peas and leaves are highly desired for consumption by consumers in both countries. In West Africa, these plant parts can be harvested during the "hunger period" before the dry grain is mature, thus providing nutritious food at a critical time. Cowpea breeders therefore need to assess the impact of green leaf and pod harvesting on overall yield when evaluating field performance of improved cowpea lines.

Food processing companies play a key role in assessing market demand and in developing value added bean and cowpea products for urban and rural consumers. With Dry Grain Pulse CRSP support, food scientists used extrusion processing methods to pilot common bean flour production and bean-based breakfast foods for markets in Central African (Uganda, Rwanda). These products reduced the effort and time required for household level cooking and food preparation. Also, value added food products enable consumers to experience increased diversity of foods in their diets and to consume more nutrient dense grain legumes. In Uganda, researchers at Makerere University collaborated with Nutreal Ltd, a private food company, to create and promote new bean-based products for local markets.

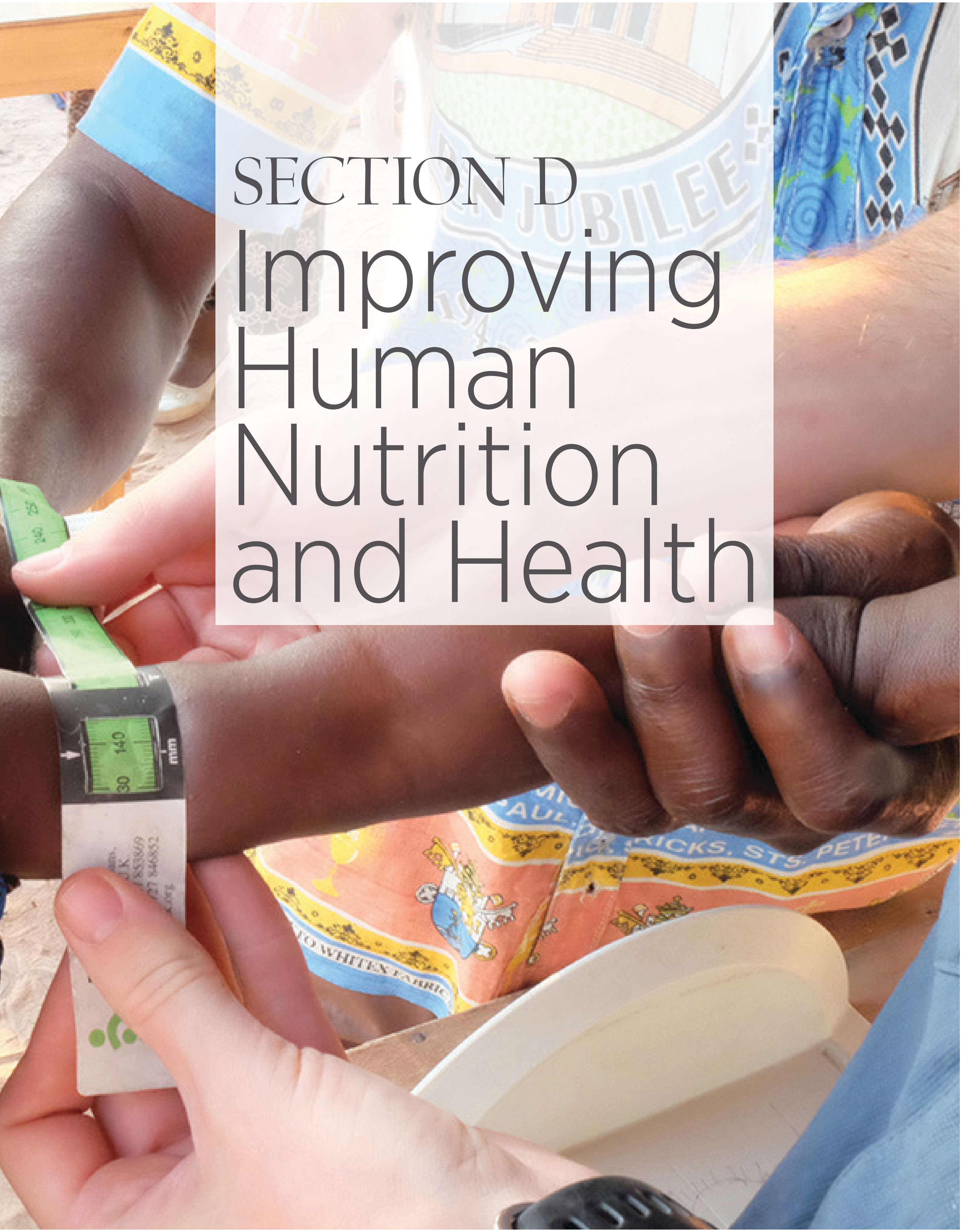
Value chain analysis elucidates how stakeholders are or might be organized, the potential roles of different agents, and the incentives for each. The LIL KSU Value Chain project organized a highly effective stakeholders' conference which led to the formation of the "Beans for Health and Wealth Association of Zambia." This multi-sectorial association comprised of farmers, seed producers, grain traders, university researchers, breeders, consumers, and processors, provides the vision, leadership, and governance structure to advance the bean sector in Zambia.

An emerging market sector with high growth potential is that of Fair Trade and certified organically produced foods sold in high value chain stores throughout the United States and Europe. Developing country grain legume farmers are well positioned to take advantage of this market opportunity because they are small-scale, have learned to produce beans and cowpeas without chemical fertilizers and pesticides, and have a story to tell to developed country consumers. A DGP CRSP study led by Drs. Rick Bernsten (MSU) and Juan Carlos Rosas (EAP-Zamorano) evaluated the economic feasibility of Fair Trade and certified organic bean production by smallholder farmer groups in Honduras, and the willingness of upscale U.S. retailers to establish contracts with these producers.

The study demonstrated that farmers in Honduras could grow beans "organically", obtain certification for organic or Fair Trade, and negotiate a contract with a higher than market bean grain price to make the enterprise profitable. The researchers were also able to identify markets for fair trade beans in the U.S. and provide guidance to Honduran farmers on the certification process. The analysis revealed that certification of organic bean production for export, however, was too expensive and difficult for small scale producers in Honduras. Fair Trade certification, on the other hand, could be a financially rewarding option, costing about $2500 for a farmer association. Honduran bean farmers ultimately were not willing to proceed to fulfill a purchase order for Fair Trade beans and sell beans at a premium to an identified U.S. buyer, and opted for selling locally. The justification for the decision was that bean grain prices spiked in Honduras in 2010 due to national shortages and smallholder farmers wanted to take advantage of the short-term market opportunity to obtain needed cash. This experience demonstrates the existence of niche market opportunities for grain legumes from developing countries but the challenge for smallholder farmer to enter into contracts that provide long-term price stability.

The findings from the portfolio of DGP CRSP and LIL research are expected to contribute to the future continued development and vitality of bean and cowpea value chains in Feed the Future countries. Continued future consumer research is needed though as societal demographics change (e.g., increase in urbanization in Sub-Saharan Africa and Latin America), as available time for food preparation declines, and as communities become more interested in the nutritional and health promoting value of diets. Grain legumes are ideal commodities to respond to these changes, but both supply and demand side players need to understand the dynamics to be positioned to effectively take advantage of the new opportunities.

Continued future consumer research is needed though as societal demographics change, as available time for food preparation declines, and as communities become more concerned about the nutritional and health-promoting value of diets



SECTION D
Improving Human Nutrition and Health

Improving Gut Health and Growth of Young Children – the Health Research Frontier for Cowpea and Common Bean {D1}

Approximately 45 percent of the 3.1 million annual deaths among children under five years are related to undernutrition. Stunting affects an additional 165 million children worldwide by reducing physical, immunological and cognitive capacity throughout life. Both stunting and wasting are causally related to the dietary intake and gut health in children under 3 years of age.

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In impoverished settings, a gut inflammatory condition, environmental enteric dysfunction (EED), often develops during the first three years of life when young children are transitioning from exclusive breast feeding to mixed feeding with solid foods. EED predisposes young children to clinically manifest forms of malnutrition including wasting and stunting. EED is characterized by a chronic inflammatory state within the intestinal system with accompanying increased intestinal permeability, entry of gut microbes into the vascular system, poor absorption of micro- and macronutrients, poor weight gain and stunted physical and cognitive development.

Unfortunately, traditional solid foods fed to infants during weaning in many Sub-Saharan countries are comprised of maize, cassava or sorghum which are low in protein and micronutrients. Starch, the primary constituent in these foods provides little more than energy and a temporary sense of satiety. On the other hand, grain legumes, such as common bean and cowpea, are nutrient-rich staple foods in these countries that could be potentially used to enhance the nutritional value of weaning foods. Since grain legumes are high in protein (23 – 25% protein of dry weight basis), essential micronutrients (Zn, Fe), vitamins and dietary fiber, cooked grain legumes could be added as a supplement to maize-based weaning foods such as hot maize porridge to improve nutritional intake and growth.

Legume Innovation Lab scientists at Washington University in St. Louis, Dr. Mark Manary, and the University of Malawi School of Medicine, Dr. Kenneth Maleta, led a clinical study in Malawi to test the hypothesis that long term complementary feeding of young children with a cowpea or bean flour would improve child nutrition, growth, and biomarkers for gut health. Malawi was chosen for the study since an estimated 13% of Malawian children are underweight, 47% are stunted, and 4% are wasted. Ongoing nutritional studies revealed that >80% of the young children in rural areas also suffer from EED.

This hypothesis has merit in light of earlier research which suggested that the enrichment of diets with grain legumes decreases markers of inflammation as well as reduces the risks of chronic illnesses with inflammatory components such as colorectal cancer and cardiovascular disease. Mechanistic molecular and rat/mouse model studies also indicated that common bean decreases inflammatory markers IL-6 and IL-8, and that the non-digestible protein fraction in beans down-regulates signaling pathways that lead to inflammation.

The Legume Innovation Lab research team conducted two long-term randomized double-blind clinical trials at two locations in Malawi to determine if the regular eating of small amounts of cowpea or common bean by young children improves growth, ameliorates EED, and alters the intestinal microbiome during the high-risk weaning period. The first study involved 291 children who received common bean, cowpea or soy-maize flours as supplementary foods for a six month period beginning at the age of six months. The second study included 329 children, 12-24 months of age when enrolled, who consumed the bean, cowpea or control supplementary food interventions for one full year. The supplementary treatment foods were prepared using either dry roasted “navy” bean or cowpea, milled into flours, according to WHO specifications but without added micronutrients. The dosages of legumes consumed daily by the children were 80 kcal/d when 6-9 mo. old, 120 kcal/d when 10-12 mo., 155kcal/d when 12-23 mo. and 200kcal/d when 24-35 mo. The supplementary food provided to the mothers was added to and mixed with hot cereal porridge that was fed daily to the children.

At regular predetermined intervals during the feeding studies, mothers brought their young children to centralized locations for anthropometric measurement (height-for-age and weight-for-height z scores), and nutrition education. Urine and fecal samples were also collected. EED was assessed using a urine-dual-sugar absorption test and by quantifying a panel human intestinal mRNA for inflammatory messages. Intestinal microbiota taxonomy (phyla to genus) were characterized and enumerated by deep sequencing of fecal DNA with the collective metabolic capacity of the microbial populations expressed as Kyoto Encyclopedia of Genes and Genomes (KEGG) categories.

Exciting findings from these two LIL studies show that:

1) The addition of cowpea (4.6-5.2 g protein/day and 4-5 g/day of indigestible carbohydrate) to complementary feeding in Malawian infants (6 to 12 mo of age) resulted in significantly less linear growth faltering (reduced stunting) by 0.13 Z-scores (Figure 5, page 60).
2) The addition of common “navy” bean to complementary feeding of rural Malawian children (12-36 months of age) led to an improvement in a biomarker of gut health. The effect size was 0.12% lactulose, although this did not directly translate in improved linear growth of infants.
3) Food metabolite analyses identified potential dietary biomarkers of legume intake for stool and urine samples that could be used to assess the relationship between distinct legume consumed and health outcomes. Dietary biomarkers of legume intake include pipecolic acid and oleanic acid for common bean and quercetin and α and γ-tocopherol acid for cowpea intake.

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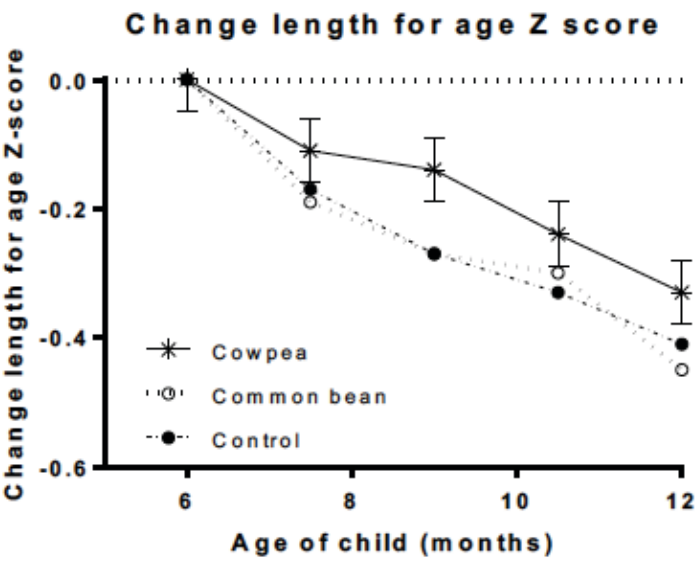

FIGURE 5. Changes in length for age Z-score of young children in Malawi as influenced by regular eating of a supplementary cowpea or common bean based food. Am J Clin Nutr: https://doi.org/10.3945/ajcn.117.160986 (2017).

These results have important implications for future nutritional interventions. Since both beans and cowpeas are locally available at low cost and the supplemental foods can be easily prepared at the community level perhaps even as a revenue generating opportunity for women, the potential for ready scale up to address child undernutrition, growth faltering and EED throughout Sub-Saharan African and Latin American countries is high.

It is imperative though that future research seek to determine if all cowpea and bean market classes (seed types) elicit similar growth and gut health responses in children living in different environments and grain legume consuming regions of the world. Moreover, research to elucidate the active constituents in grain legumes and the biochemical mechanisms for these human physiological responses might enable plant breeders to genetically improve the health-promoting value of grain legumes.

Cooking Time and Culinary Traits in Beans Matter – Using Breeding to Improve Quality {D2}

Cooking time, gravy thickness and flavor of beans and cowpeas are important to both smallholder farmers and consumers. Culinary traits of grain legumes influence farmer selection of varieties to plant, household consumption and market demand in Sub-Saharan Africa and Latin America. Social scientists, dieticians and development professionals recognize that improving culinary attributes of beans and cowpeas is essential for increasing consumption and improving the nutrition and health of vulnerable populations in Feed the Future countries. Culinary traits are, however, influenced by numerous factors including growing environment, grain storage conditions, cooking method, and the genetics of the crop or variety.

The Legume Innovation Lab sought to improve the culinary characteristics of common bean by focusing on the breeding of varieties with flavor and cooking quality attributes preferred by local consumers. These culinary traits can be genetically "locked in" so as to ensure that consumers have sustainable access to bean and cowpea varieties that they like to cook and eat.

There are two formidable challenges, however, associated with the breeding of culinary traits. First, many culinary traits are subjective. Consumer preferences for bean market class, gravy thickness and flavor differ from one country or region to another. Secondly, the measurement of culinary traits and selection of lines with the preferred combination of desired traits is slow and costly.

Through the leadership of Dr. Karen Cichy, a USDA/ARS scientist at Michigan State University working with Legume Innovation Lab scientists in Uganda and Zambia, a dynamic post-harvest, high throughput visible/near infrared spectroscopy imaging technology (HYPERS) was developed to phenotype bean breeding lines for cooking traits. HYPERS was shown to effectively estimate water uptake and cooking time of dry beans samples in a nondestructive, reproducible, rapid and low-cost manner. Phenotyping of 140 lines from four market classes of beans Andean bean lines from Tanzania and the U.S. showed that cooking times varied from approximately 20 to 160 minutes. The Legume Innovation Lab believes that the HYPERS technology will be game-changer for grain legume breeding programs, providing breeders with a tool that will mainstream the assessment and selection of breeding lines for preferred cooking attributes.

HYPERS was shown to effectively estimate water uptake and cooking time of dry beans samples in a nondestructive, reproducible, rapid and low-cost manner.

Phenotyping of 140 lines from four market classes of Andean bean lines from Tanzania and the U.S. showed that cooking times varied from approximately 20 to 160 minutes. The Legume Innovation Lab believes that the HYPERS technology will be a game-changer for grain legume breeding programs, providing breeders with a tool that will mainstream the assessment and selection of breeding lines for preferred cooking attributes.

Participatory selection of breeding lines is also an effective approach to evaluate and select lines with the desired combinations of culinary traits. In Uganda, an initial selection was made of 23 bean lines of various market classes from the Andean Diversity Panel identified to have shorter cooking times and relatively higher mineral bioavailability (especially iron). These lines were planted in trials in three agro-ecologies in Uganda and farmers rated their seed quality preferences at harvest. Farmers preferred seven lines, as they combined agro-ecological adaptability with shorter cooking times.

Sensory evaluations have also been conducted with large populations of farmers and consumers in Uganda and Zambia. Through the use of these participatory assessments and analytical data from laboratory analyses of mineral bioavailability, the Dr. Cichy-led research team was able to identify genotypes that were preferred for taste, cooked faster and had improved nutritional quality traits.

The Legume Innovation Lab anticipates a day in the near future when grain legume breeders will regularly screen breeding lines for cooking and culinary traits as standard practice to ensure that new varietal releases will be sought out by consumers and possess culinary quality attributes demanded by markets.

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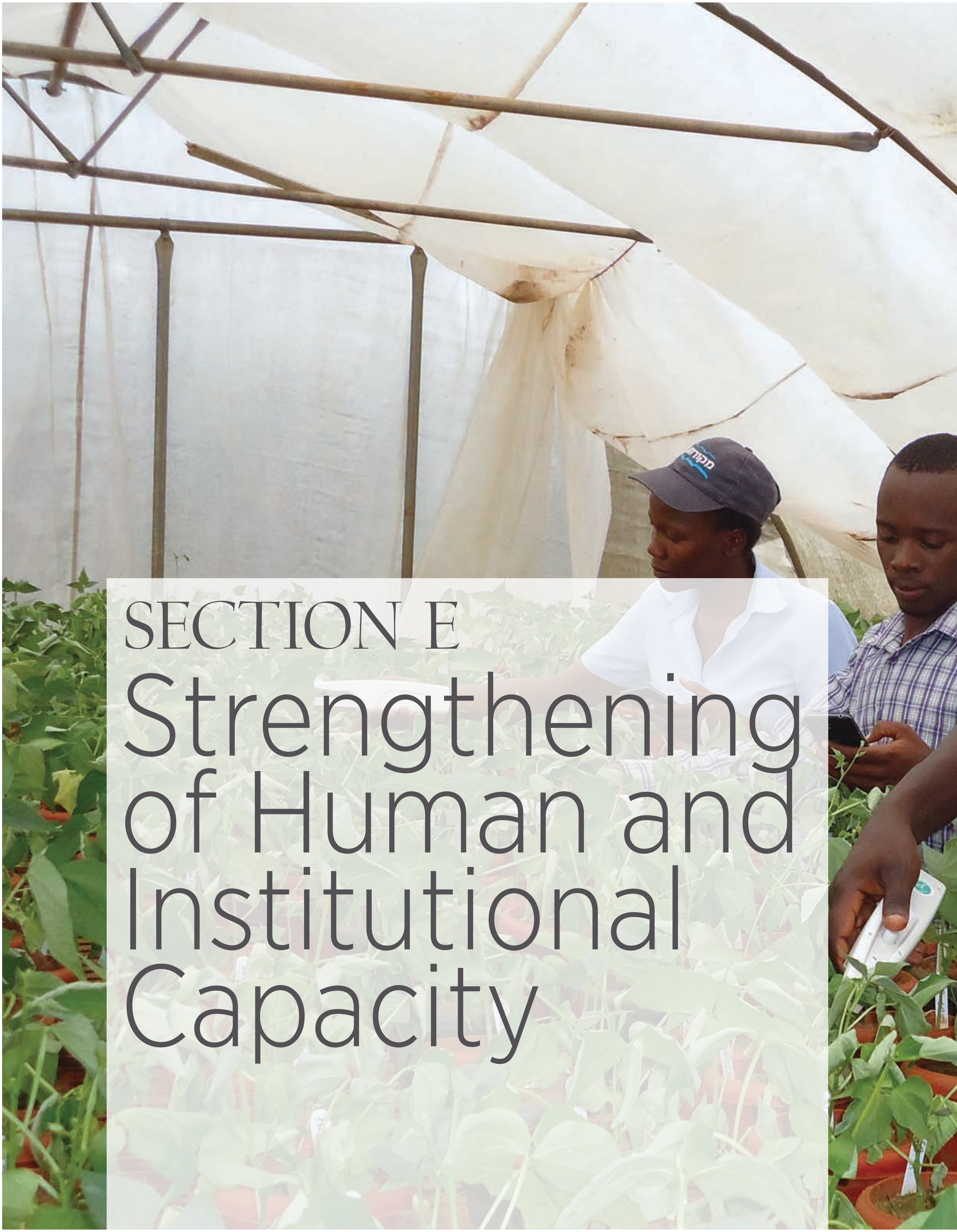


SECTION E
Strengthening of Human and Institutional Capacity

A Living Legacy: Formation of a New Generation of Grain Legume Scientists and Sector Leaders {E1}

Human resource development and institutional capacity strengthening are never ending tasks that must be priorities of USAID Innovation Labs. Partner agricultural research institutions in Innovation Labs, such as national agriculture research organizations (NAROs) and research intensive universities need and greatly benefit from investments in human resource development. The rapid rate of new knowledge generation, the development of new research tools and analytical technologies, and the emergence of new frontiers in science require that research institutions be continually upgrading their existing staff and hiring a new generation of scientists with knowledge and skill sets to effectively use modern science to address challenges facing agriculture. Some of the frontiers in agriculture and nutrition science that emerged just in the past 10 years, the life of the DGP CRSP and LIL, include genomics, gene editing, physiological phenotyping, metabolomics, nano-technology, crop and systems modeling, large multi-variant data set analyses, remote sensing, communications technology, value chain innovations, and gut microbiome ecology. It is imperative that developing country scientists and institutions also have the capacity to take advantage of these cutting edge research tools to develop innovative technologies and robust solutions to the recalcitrant problems in agriculture, public health and nutrition.

A commitment to the preparation of a new generation of grain legume scientists to be innovators and thought leaders and of business persons to lead grain legume value chain sectors into the future has been a hallmark of the Dry Grain Pulses CRSP and Legume Innovation Lab. All scientists in the program, whether U.S. or host country, share a common vision for the importance preparing a new generation of scientists. Perhaps this is due to the fact that projects are led by university faculty who are both researchers and educators driven by a desire to pass on their knowledge and research skills and to mentor young people who will return to their home countries and make a difference.

The human resource capacity strengthening strategy of the DGP CRSP and LIL has been multi-faceted, investing in both long term tertiary degree education as well as short term training activities to address technical capacity needs of a broader population (i.e., technicians, extension specialists, leader farmers, etc.). This commitment is evidenced by the fact that greater than 30% of all direct funds to subcontracted projects was utilized to support both degree and short term training for the benefit of developing country partner institutions, government agencies, private business and development organizations serving the grain legume sectors. In addition, projects integrated innovative educational approaches so as to enhance learning and lower cost. Examples of such innovations include distance learning graduate programs (e.g., KSU's master's program in Business Management), sandwich degree programs, training in research methods for technical support staff, and short-term research visits by HC scientists in U.S. university laboratories.

Advanced degree training has been at the core of the CRSP and IL model for capacity building because of the integral relationship between the formation of young scientists and the achievement of program research objectives.

All students in degree programs were actively involved in research on grain legumes, whether through the completion of thesis research projects, assisting the major professor as 'research assistants' to carry out his/her research program commitments, or by returning to a host country to lead field research activities associated with projects. The active participation in research and the learning of skills associated with the management of a productive research program (including proposal writing, the design of experiments, maintenance of research equipment, conducting laboratory analyses, carrying out field surveys, training of research technicians or enumerators, statistical analysis and interpretation of data, writing and presentation of findings, interactions with peer scientists, etc.) are considered equally important to the education of a graduate student as the course work that they complete. Moreover, faculty mentors also benefit from the interactions with the international graduate students by learning of the problems and opportunities facing the grain legume sectors in the target FTF countries.

The output from investments in degree training by the DGP CRSP and LIL are impressive and will have impact on the grain legume sectors in Africa and Latin America. A total of 201 students have completed degree programs with full or partial funding from the program (see Table 4). The majority of students were trained in FTF countries, especially at advanced universities in the respective regions (e.g., EAP-Zamorano in Honduras, Makerere

	DGP CRSP FY2008-2012		LEGUME INNOVATION LAB FY2013-2017	
Students by categories	**Number**	**%**	**Number**	**%**
Gender				
Female	29	46%	59	43%
Male	34	54%	79	57%
Region of Origin				
East Africa	19	30%	17	12%
Southern Africa	23	37%	36	26%
West Africa	11	17%	46	33%
Latin America/Caribbean	5	8%	32	23%
United States	2	3%	7	5%
Other	3	5%	0	0%
Degree program				
BS	12	19%	42	30%
MS	41	65%	61	44%
PhD	10	16%	35	25%
Training Location				
US	18	29%	27	20%
Host Countries	37	59%	110	80%
Third countries	8	13%	1	1%
Total	**63**		**138**	

TABLE 4: Degrees Completed with DGP CRSP and LIL Sponsorship
Two students went directly from MS to PhD and thus only counted as having completed PhDs. Five Legume Scholars and three LIL trainees had not completed PhD programs as of 11/30/2017.

The leadership roles and the achievements of the 201 individuals that received degrees (through the DGP CRSP and LIL) will leave a lasting and ongoing "footprint" on the growth of grain legume value chains.

University in Uganda, Lilongwe University of Agriculture and Natural Resources (LUANAR) in Malawi, and the University of Zambia). The total number of degrees completed was actually higher since certain students pursued consecutive MS and PhD degree programs with DGP CRSP and LIL support. In many instances, PIs leveraged resources from other sources in order to share the costs for the training. This accounts for the significant number of BSc degrees completed at undergraduate institutions such as EAP-Zamorano. It is also noteworthy that 84 and 71 percent of degrees were awarded to persons from Sub-Saharan Africa during the DGP CRSP and LIL phases, respectively, indicating a program commitment to capacity strengthening in Western, Eastern and Southern Africa.

One example of effective coordination of degree training between USAID programs was that of Isaac Dramadri, who defended his PhD thesis at Michigan State University in plant breeding and genetics in February 2018. He has accepted a post-doc appointment as a cowpea breeder at Makerere University and thus returning to his home country of Uganda. As a graduate student of Dr. James Kelly, he conducted his thesis research on the genetics of drought tolerance in common bean, a research objective of the Kelly-led LIL collaborative research project with NaCCRI in Uganda. Isaac's educational expenses were covered through a scholarship from the Borlaug Higher Education for Agricultural Research and Development (BHEARD) program while his research expenses were funded by the LIL. Isaac best articulated the value of his graduate experience: "I did not come to MSU for just a PhD title" but rather for "the field experience and the science that has empowered me to continue research on beans and other legumes . . . and will enable me to work to improve the livelihoods of people." He also appreciated that Dr. James Kelly helped him design his own research project but then said "off you go" to conduct his field work in Uganda. This is the sign of a true mentor: one who guides a student through their academic graduate program but then allows the student to assume responsibility and ownership for the research project.

The rapid rate of new knowledge generation, the development of new research tools and analytical technologies, and the emergence of new frontiers in science require that research institutions be continually upgrading their existing staff and hiring a new generation of scientists with knowledge and skill sets to effectively use modern science to address challenges facing agriculture.

In view of the need for a new generation of young grain legume scientists, the Legume Innovation Lab at Michigan State University partnered with the CG's Consortium Research Program on Grain Legumes, administered by

ICRISAT, and the Peanut and Mycotoxin Innovation Lab at University of Georgia to establish an innovative jointly-funded new PhD scholarship program. Academically excellent students with a demonstrated commitment to grain legume research were selected and enrolled in PhD programs in diverse disciplinary areas. Candidates to be considered for the Legume Scholars Program (LSP) scholarships were nominated by grain legume scientists working in Africa, Latin America and Asia. The five scholars chosen began their programs in 2015. Each scholar is being advised by an Innovation Lab PI at a U.S. university along with an assigned CGIAR grain legume scientist serving on the guidance committee. When the performance period for the Legume Innovation Lab ended, USAID issued a "Legume Scholars Program associate award" to Michigan State University to support the LSP students through the end of their graduate degree programs in 2019.

The Legume Scholars Program scholarship recipients are:

- Rosemary Bulyaba from Uganda, Agronomy, Iowa State University
- Aggrey Gama from Ghana, Food Science, University of Georgia
- Pacem Kotchofa from Benin, Agriculture Economics, Kansas State University
- Susan Moenga from Kenya, Plant Genetics, University of California Davis
- Isaac Osei-Bonsu from Malawi, Plant Physiology, Michigan State University

The broad disciplinary focus of the graduate programs of this cohort ensures that African institutions will be able to address a broad range of constraints and opportunities facing the grain legume sectors in the future. All of the Legume Scholars participated and presented in the 2017 LIL Grain Research Conference in Burkina Faso, enabling them to network and form professional linkages with the international grain legume research community.

Short term training activities are complementary to degree training by reaching a broader population of grain legume investigators, technicians, development specialists, extension educators, etc. The short term training activities focused on developing needed skills and knowledge on the use of outputs from DGP CRSP and LIL research. The majority were held in host countries in order to achieve economies and be locally relevant. During the DGP CRSP phase, approximately 60 short term training activities were completed reaching over 15,000 people, with an additional 11,000 persons benefitting from over 70 short term training activities during the LIL phase. Innovation Platforms (see Section C.1) were shown to be effective in reaching farmers and actors in grain legume value chains.

Examples of noteworthy short term training activities include:

- Use of information and communications technologies (ICT) to implement biocontrol based integrated pest management (IPM) strategies for managing cowpea insect pests in Burkina Faso, Ghana, and Niger
- Methods for phenotyping and screening bean breeding lines for drought and disease resistance in Zambia
- Methods for soil classification utilizing observable characteristics along with soil maps, analyses of soil samples, and farmer knowledge to develop appropriate integrated soil and crop management practices in Mozambique
- Design and implementation of household surveys to collect baseline data in Mozambique
- Practices for the multiplication, conditioning and handling of basic and registered bean seed held at EAP-Zamorano in Honduras
- Co-hosting of the Common Bean Disease Workshop on Angular Leaf Spot and Root Rot in South Africa with USDA-ARS

What will be the legacy of the Dry Grain Pulses CRSP and the Legume Innovation Lab in 10 or 20 years? Unquestionably, a major part of that legacy will the performance and impacts of the developing country institutions that were strengthened through the human resource capacity investments by the program. The leadership roles and the achievements of the 201 individuals that received degrees will leave a lasting and ongoing "footprint" on the growth of grain legume value chains and on improvements in smallholder farmer livelihoods and the food and nutritional security of countries in Sub-Saharan Africa, Central America and the Caribbean.

Small Competitive Awards Strengthen Host Country Institutional Research Capacity {E2}

An innovative initiative of the Dry Grain Pulse CRSP and Legume Innovation Lab was the annual competitive allocation of small grants to host country partner institutions to strengthen grain legume research capacity. The intent of these Institutional Capacity Strengthening awards was to address critical and frequently unanticipated needs of Host Country (HC) institutional collaborators which exceeded the budgetary limits of subcontracted projects and to respond to opportunities to strengthen the grain legume research capacity of partner agricultural research institutions in USAID priority countries.

The responses by both HC and US PIs to the annual solicitations of Capacity Strengthening proposals were enthusiastic. The Management Office tasked the Technical Management Advisory Committee (TMAC) with the review of the proposals and for recommending awards each year. The TMAC gave priority to: 1) innovative training activities for individual HC scientists, including short-term training in centers of excellence and research internships; 2) innovative training for HC research teams through workshops or short-courses on topics relevant to research; and 3) acquisition or rehabilitation of critical research or teaching supplies and equipment (valued greater than $5000). Generally, awards ranged from $15,000 - $45,000, with a few exceptions, and funds were provided directly to individual HC partner institutions.

Host country PIs valued these investments, and the opportunity that they afforded to address critical training and research supply/equipment needs that arose during the implementation of a DGP CRSP or LIL project. Since project budgets were frequently constraining, the capacity strengthening awards provided access to additional funding to do innovative things that would benefit their grain legume research and educational efforts over the long term.

Over $608,000 for 26 projects were committed to capacity strengthening investments during the DGP CRSP from 2008-2012, and another $680,000 for 36 projects during the Legume Innovation Lab from 2014-2017 (Table 5). The annual technical highlights reports detail how the funds were allocated. Approximately 18 different collaborating host country institutions in all projects benefitted from and received one or more awards over the 10 year performance period.

FY2009	$176,466
FY2010	$72,500
FY2011	$252,097
FY2012	$107,371
FY2014	$239,686
FY2015	$279,806
FY2016/17	$159,138
Total	**$1,287,064**

TABLE 5: Funding allocations by DGP CRSP and LIL to small institutional capacity strengthening awards.

Specific examples and testimonials that give evidence of the value to Host Country Institutional Capacity Strengthening awards include:

- A new autoclave was purchased by EAP- Zamorano in Honduras to replace a decades-old instrument. Dr. Hincapie stated that the autoclave "is essential for our bean research program's activities dealing with the isolation and characterization of fungal and bacterial pathogens causing diseases on common beans . . ."

- A four wheel drive vehicle purchased by the IIAM Bean Research program was critical for conducting field research in remote rural areas including the FTF priority area of Zambezia Province in Mozambique, given the poor quality of roads and long travel distances involved.

- Insect rearing facilities and solar generator for the Entomology Lab at INERA-Burkina Faso. Dr. Fousseini Traore said that "Before we received these awards, it was impossible for INERA to maintain cowpea insects in continuous rearing over the year. But to date, that difficulty belongs to the past."

- Specific training activities supported with Institutional Capacity Strengthening funds included (1) a short course on food safety and grain legumes at the University of Malawi School of Medicine, (2) a workshop on the indigenous soil classification methods in Kenya, and (3) training on analytical methods assessing the adoption and impact of agricultural technologies was conducted at UNZA in Zambia.

- Graduate student and early career scientist participation in international scientific meetings. Travel expenses and registration fees were covered for a significant number of LIL supported trainees and HC PIs to present their research findings at the 2016 Pan African Grain Legume Conference, and the annual PCCMCA meetings in Central America.

- Replacement pumps or other irrigation components were essential for ICTA in Guatemala, IIAM in Mozambique, and University of Zambia to conduct drought studies and to produce breeder and foundation seed of improved bean varieties. The rehabilitation of the irrigation system at the University of Zambia, enabled Dr. Kamfwa to phenotype bean breeding lines for response to drought and low soil moisture.

- The rehabilitation of screen houses at ISRA-Senegal and INERA-Burkina Faso greatly enhanced the capacity of the cowpea breeding programs to screen for insect resistance and to prevent exposure to insect species which are vectors of disease.

This initiative gives evidence of the DGP CRSP and LIL's commitment to and leadership in implementing innovative approaches to strengthen the grain research capacity of collaborating national agriculture research organizations and agricultural universities in Feed the Future countries. With a relatively small investment of funds, the program was sensitive to and effectively responded to the needs of partner institutions a manner that will bring long term dividends.

Cross-Training and Multidisciplinarity – An Innovative Approach to Link Agriculture and Nutrition {E3}

A strategic theme of the US Government's Feed the Future Research Strategy (2011) was to enhance nutrition and food safety. The strategy recognized the important role that agricultural systems play in public nutrition and health and sought to direct efforts to "improving availability and access to high quality diets, particularly for women and young children." The focus of the research strategy was to invest in the diversification of agricultural production systems, enhancing dietary diversity with nutrient dense foods, and reducing postharvest losses."

Since grain legumes (common bean, cowpea, pigeon pea, chickpea, etc.) are nutrient-rich traditional staple foods in the diets of many food-insecure populations in Africa, Latin America and Asia, USAID invested in the Dry Grain Pulses CRSP and the Feed the Future Legume Innovation Lab. The challenge, however, was to ensure that the technologies being generated by the DGP CRSP and LIL would contribute to increased consumption of beans and cowpeas and therefore to improved nutritional security by undernourished and vulnerable populations in FTF countries.

MASFRIJOL, an associate award by the USAID Mission to Guatemala (4/1/2014-3/25/2018) to the LIL Leader Award, was a project that fulfilled FTF's vision of linking agriculture and nutrition. MASFRIJOL's dual objectives were to increase bean productivity in highland cropping systems and to enhance the nutritional quality of diets through increased access to and consumption of beans. The Western highland region of Guatemala was the focus of the USAID Mission's FTF program due to the high incidences of undernourishment and child stunting among the Mayan populations. The vision for MASFRIJOL was

to deploy the technologies and expertise on common bean of the Legume Innovation Lab to address the food and nutritional security challenges of this region.

Increasing common bean access was considered to be a solution because bean productivity was extremely low in the traditional "milpa" intercropping system, and local bean prices were consequently high and thus unaffordable to rural Mayan households. Beans would also be an acceptable complementary nutritious food to maize-based tortillas in Mayan diets.

Although MASFRIJOL effectively utilized several interventions to achieve its bean productivity and nutrition goals, including the dissemination of high yielding black bean varieties, the establishment of community based seed production, and nutrition education interventions, the true innovation in the project was its approach. Agronomic extension specialists, nutrition educators, public health technicians, and rural development specialists from public and private partner institutions were cross-trained and actively participated in the implementation of project activities within the communities.

Cross-training by definition is the teaching of personnel to perform multiple functions. By cross training and engaging technicians with different technical expertise, MASFRIJOL's vision was to link the bean productivity and nutrition efforts in a mutually reinforcing manner to sustainably achieve the project's objectives.

At the inception of MASFRIJOL, LIL PIs consulted with potential implementing partners in Guatemala including staff from the Ministry of Agriculture, Livestock and Food (MAGA), the Ministry of Public Health (MSPAS), and USAID FTF development partners. It was immediately discovered that two critical populations of technical specialists rarely interacted and collaborated, namely agricultural technicians and community nutrition/health educators. When the vision and objectives of MASFRIJOL were presented, representatives from these governmental and NGO partners immediately comprehended the genius of focusing on common beans to overcome the pervasive undernutrition among children in the Western highlands. The problem articulated by all, however, was that field technicians never receive multi-disciplinary training and thus feel incapable of contributing to initiatives with dual agriculture productivity and nutrition objectives.

> Cross-training and the use of multidisciplinary mixed-gender teams unquestionably enhanced the efficacy of MASFRIJOL in achieving its dual agriculture productivity and nutrition objectives within the Mayan communities.

MASFRIJOL's novel approach for linking agriculture and nutrition was to:

1. Provide cross-training on human nutrition/dietetics and agronomic practices for bean production to agronomists, public health technicians, and nutrition educators from partner organizations through a series of four workshops. Within the project, >100 persons have received training.

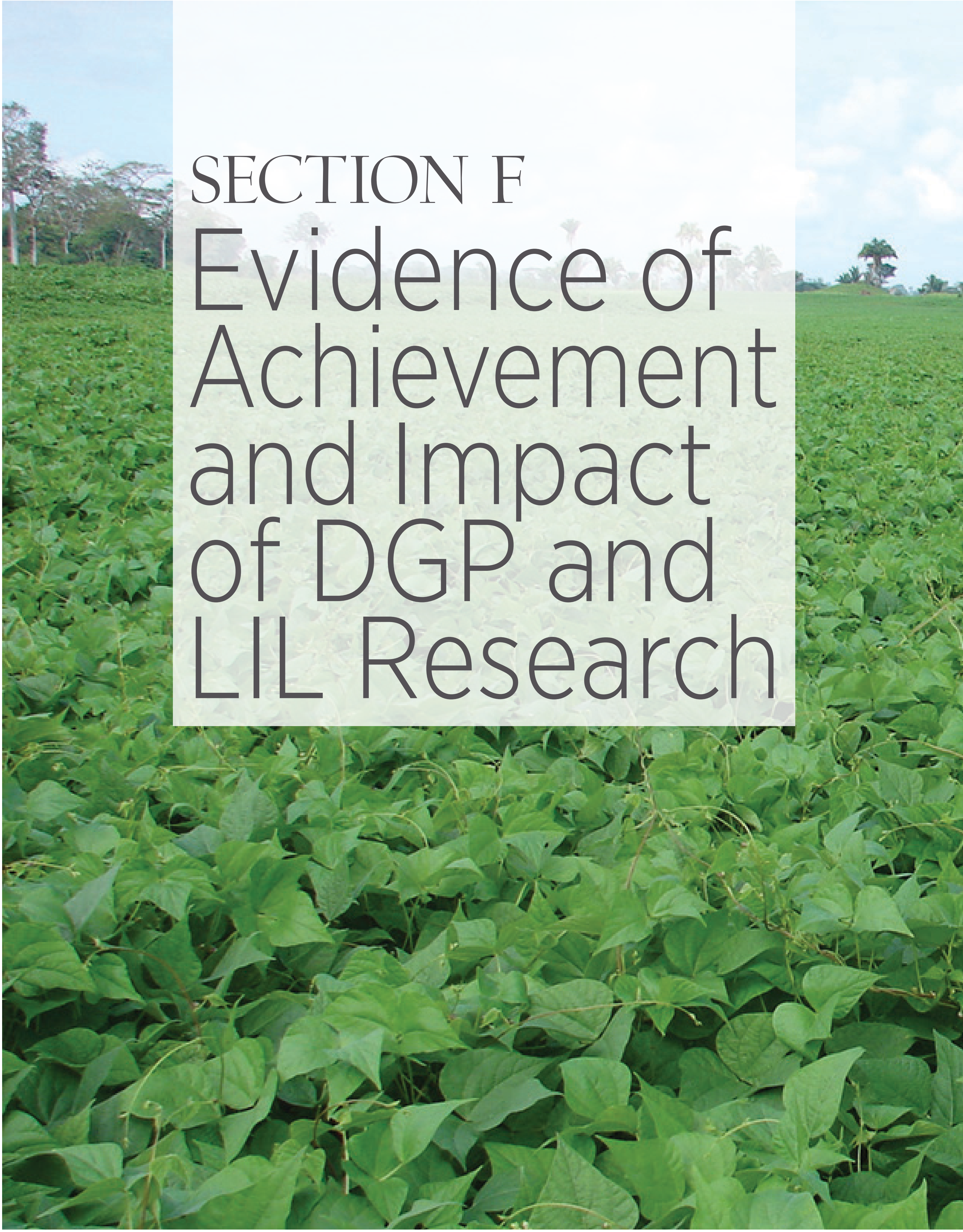
2. Develop five nutrition and eight agronomy lesson plans plus accompanying educational activity plans jointly with partners for use with communities. The nutrition lessons focused on increasing the understanding of chronic malnutrition, protein quality of foods, complementary feeding of infants, nutritional value of beans, integration of bean-based foods in diets (with recipes), and dietary diversity.

3. Utilize multi-disciplinary teams of women and men to teach lessons and lead community-based activities on quality bean seed production, household bean grain storage, increasing bean productivity through the planting of improved bean varieties, the preparation of bean-based foods utilizing locally available ingredients, etc.

Cross-training and the use of multidisciplinary mixed-gender teams unquestionably enhanced the efficacy of MASFRIJOL in achieving its dual agriculture productivity and nutrition objectives within the Mayan communities. Nutrition educators contributed to the promotion of improved bean varieties and quality seed because it would lead to greater household access to beans and enhance the nutritional quality of the diets. Agronomic extension specialists could also encourage farmers to utilize bean yield enhancing technologies because beans are highly nutritional.

An important lesson learned from the MASFRIJOL experience was that "community trust" is highly important for advancing an agriculture development agenda. Within a rural community, such as the Mayan communities in Guatemala, the most trusted individuals were the health and nutrition specialists who worked in local health clinics. When these health professionals shared with mothers and fathers in the community about the importance of producing and eating more beans to improve the growth and health of their children, they listened and frequently acted.

SECTION F
Evidence of Achievement and Impact of DGP and LIL Research



Impacts from Grain Legume Research: Impact Pathways and Assessments {F1}

The Global Food Security Research Strategy (GFSRS) of Feed the Future establishes a conceptual framework for ensuring that new technologies resulting from investments in research achieve their intended development outcomes and impacts: "a Research and Development (R&D) pipeline." Within a pipeline, "new technologies are advanced through phases of basic, applied and adaptive research before being transferred to technology-scaling partners for dissemination and ultimately being adopted by developing-country beneficiaries" (US Government September 2016). While the GFSRS strategy is relatively new, the key concepts of the pipeline were embodied in the innovative impact pathways and impact assessments of the DGP CRSP and LIL.

Each LIL project was required to define an "impact pathway" for their research outputs to ensure that Principal Investigators (PIs) understood the steps, partnerships and pass-offs necessary for a technology to be developed, field tested and ultimately scaled up to achieve the intended impact (Figure 6). Since the CRSPs and ILs are fundamentally agriculture research and capacity development programs, USAID's Bureau for Food Security does not require project PIs to be responsible for scaling up and impact. The impact pathways, however, play an important role of helping PIs to envision the end impact goals for their research outputs, to assess what is needed to position the technology for commercialization and scaling up in the future, and to design their technology development activities with these insights in mind.

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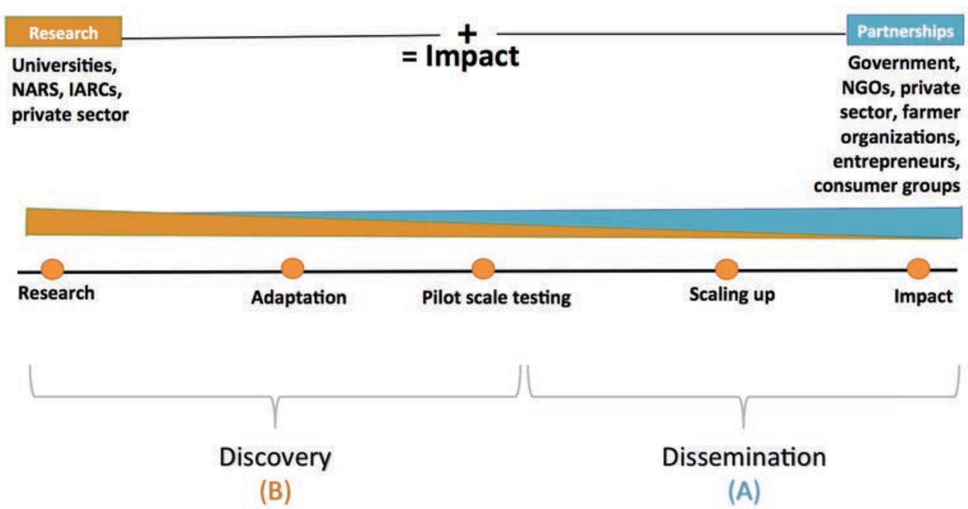

FIGURE 6: Impact Pathway Model Used by Legume Innovation Lab.

Dr. Mywish Maredia, an impact specialist at MSU and a PI in LIL, assisted the project research teams to think through and define an impact vision, timeline, strategies and action plans for each key technology within a project. At periodic times during project implementation, the MO requested updates to ensure that PIs revisited the established impact pathways and evaluated whether they were on target.

Dr. Maredia and her team were also tasked with ex ante and ex post impact assessments for both the DGP CRSP and LIL. Ex ante impact assessments helped guide future research investment decisions by the Management Office and USAID. Ex post impact assessments provided valuable information on the adoption and success of past technologies developed under the Bean/Cowpea and DGP CRSPs and learned lessons from technology design and scaling up activities.

An example of an effective design and implementation of an impact pathway was the "IPM-omics- Scalable and Sustainable Biological Solutions for Pest Management of Insect Pests in Cowpea in Africa" project led by Dr. Barry Pittendrigh (University of Illinois at Urbana Champaign and Michigan State University) (see Section B.5). Through collaborative research with IITA-Benin and scientists in Burkina Faso, Ghana and Niger, biologicals were developed to control cowpea pod borer (*Maruca vitrata*). The project team realized early on that the implementation of an effective IPM program necessitates a coordinated regional effort involving national agriculture research organizations, extension specialists, and farmers. The challenge was to deploy multiple biologicals (parasitoids, neem oil, *M. vitrata* virus) in a time sensitive manner to a cowpea crop at a critical stage of development to control a migratory insect. This requires extensive knowledge of factors influencing the efficacy of biocontrol technologies and communication of knowledge to diverse end-users with varying levels of literacy.

An impact pathway analysis by Dr. Pittendrigh highlighted the need to educate smallholder farmers to affect behavior change, since the use of synthetic chemical pesticides would kill the parasitoids and thus undermine the IPM strategy for controlling the pod borer. Training materials utilizing video animations for low education farmers were therefore prepared by the team with the assistance of social scientists. These videos were field tested and utilized in farmer field schools and other extension activities throughout the region. Guided by the impact pathways, the PIs were able to identify key leverage points and potential blockages to eventual scaling up of the biological agents, important for achieving regional pest control on cowpea farms in West Africa.

Given the long term investments in grain legume breeding and in controlling the cowpea storage weevil by the Bean/Cowpea CRSP, the DGP CRSP and LIL, ex post impact assessments were conducted on dissemination and adoption of common bean varieties in Central America and Ecuador, cowpea varieties in Senegal, and of the hermetically sealed cowpea storage bag technology in West Africa.

Ex post assessments revealed high rates of return on key R & D investments by the CRSPs.

1. Early maturing, semi-erect improved cowpea varieties 'Mouride' (1991), 'Melakh' (1995), and 'Yacine' (2005), were developed and released by ISRA-Senegal with B/C CRSP assistance. DGP CRSP investments enabled ISRA to increase breeder and foundation seed of these varieties, and to coordinate seed multiplication with a network of farmer organizations and NGOs. An estimated 50 to 60 percent of Senegal's annual

demand for certified cowpea seed was met with these improved varieties. By 2010, cowpea varieties developed with CRSP support represented 42 percent of total land area planted to cowpeas in three key production areas. The present value of net benefits was estimated to be at least $78.6 million with an internal rate of return of 17.9 percent, when projecting benefits through 2020, based on high adoption rates of improved varieties with yield benefits.

2. Between 1990 and 2010, seventy-eight improved bean varieties were released in Central America and Ecuador including 45 small-reds and ten red-mottled bean varieties with assistance from the B/C CRSP, DGP CRSP and CIAT. A 2011 survey of farmers revealed that 67 percent of the small red bean cultivated area was planted to improved varieties in Central America and 50 percent of the red-mottled area in Ecuador by 2010. Taking into account the costs of research investments, a regional net present value of these improved varieties was estimated at US $359 million, representing an internal rate of return of 32 percent, a solid investment in public sector research with NARS.

3. DNA analysis of seed samples collected from farmers and in markets was shown by the M. Maredia research team as an effective way to identify varieties and estimate their adoption in countries where varietal names have been lost. Each variety has a unique DNA "fingerprint" which can be rapidly measured with a high degree of accuracy. A LIL study in Haiti in partnership with the National Seed Service is using this methodology along with farmer surveys to determine the adoption of small black bean varieties with BCMV and BGYMV resistances introduced by the DGP CRSP and LIL, and their contributions to potential increases in productivity and food security by smallholder farmers.

In spite of the fact that impact assessments require a portion of the research budget of an Innovation Lab and are frequently conducted many years after the commercialization of a technology, the data generated are vitally important to USAID for justifying future investments in these programs. Clearly plant breeding and genetics research have been worthy investments by the DGP CRSP and LIL as evidenced by the impressive inventory of technological outputs; improved varieties of bean and cowpea, breeding lines developed and molecular markers developed for economically important traits (see Sections B.1, B.2 and B.6). Future impact assessments should also focus on other DGP CRPS and LIL outputs that are more challenging to document and quantify including public goods (e.g., new knowledge generated on child nutrition/health and farmer decision making), strengthened research institutions from investments in training, and on improvements in sustainability and resilience of smallholder grain legume-based farming systems and value chains.

References:
U.S. Government (USG). September 2017. The US Government's Global Food Security Research Strategy. Washington, DC: USG. https://feedthefuture.gov/sites/default/files/resource/files/GFSS_ResearchStrategy.pdf

Benefits to the “Bean” Industry in the United States {F2}

The Dry Grain Pulses Collaborative Research Support Program (DGP CRSP) (2007-2012) and the Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (Legume Innovation Lab- LIL) (2013-17) program have consistently supported the interests of agriculture in the United States, developing innovative technologies/management practices/new knowledge that directly benefit commercial “bean” industries. According to U.S. industry lexicon, “beans” include such tropical legumes as common bean (*Phaseolus vulgaris*), cowpea/blackeye pea (*Vigna unguiculata*), and lima bean (*Phaseolus lunatus*) which have been focal grain legume crops for the DGP CRSP and LIL research program.

Strategic objectives for the Legume Innovation Lab, a USAID/Bureau for Food Security sponsored program, has been to increase dry bean yields, farm profitability and sustainability, and household consumption for improved nutrition and health. Since USAID is the primary federal agency that has financially supported research on beans at U.S. universities, the U.S. dry bean industry recognizes and highly values USAID’s commitment to this important commodity sector.

USAID derives its authorization to support the FTF Legume Innovation Lab through Title XII, an amendment to the Foreign Assistance Act (1961), “Famine Prevention and Freedom from Hunger” that was signed in 1975 and amended in 2000. This legislation establishes a leadership role for U.S. universities in achieving the goals of “ensuring food security, human health, agriculture growth, trade expansion and the sustainable use of natural resources” in support of both developing country **and U.S. agriculture.** To that end, a fundamental goal of the Legume Innovation Lab has been to achieve dual benefits to Feed the Future focus countries as well as to the “bean” sector in the U.S. To achieve this goal, approximately 45% of all research funds through the Legume Innovation Lab are awarded to 11 U.S. universities with the balance going to partner collaborating developing country institutions.

Benefits to U.S. agriculture derived from the Legume Innovation Lab can be grouped into three categories; (1) benefits to public bean breeding programs at U.S. universities, (2) strengthened research capacity at U.S. universities and (3) benefits to the U.S. dry bean industry (comprised of growers, traders and processors of dry beans). The following outlines some of the numerous benefits under these three categories.

1. Benefits to public bean/cowpea breeding programs at U.S. universities

Within the United States, the breeding of beans and cowpeas has historically been tasked to public land-grant universities which assume responsibility for the genetic improvement and release of improved high yielding varieties with the desired agronomic and culinary traits for commercial production. This is largely due to the limited private sector investment in the breeding of edible grain legumes (excludes soybean) within the U.S., even though they are vitally important for soil health, cropping system sustainability, income generation and human nutrition.

The DGP CRSP and LIL research investments have primarily focused on genetic improvement and the introduction of improved bean and cowpea varieties in target developing countries and the United States because of the tremendous potential of this technology to increase productivity and thus farm incomes.

> The DGP CRSP and LIL have financially supported the primary public bean and cowpea breeding programs in the U.S. that develop the overwhelming majority of bean varieties grown commercially in the U.S.

The DGP CRSP and LIL have financially supported the primary public bean and cowpea breeding programs in the U.S. that develop the overwhelming majority of bean varieties grown commercially in the U.S. These include the common bean breeding programs at Michigan State University, North Dakota State University, University of Nebraska, and the University of Puerto Rico, plus the cowpea breeding program at the University of California-Riverside. LIL also supported collaborations with USDA-ARS bean scientists at TARS/Puerto Rico, Prosser/Washington and MSU/Michigan which facilitated complementarity and coordination of bean genetic improvement research in the U.S. Benefits derived by U.S. agriculture from DGP CRSP and LIL support of these breeding programs include:

A. Access to grain legume germplasm with desired traits and genetically improved varieties— For breeding programs to make genetic advances and release new varieties, they require access to germplasm with genetic diversity. Through the DGP CRSP and LIL, U.S. university breeders have accessed diverse new germplasm by collaborating with breeders in Central America and the Andean Region of South America, centers of origin of common bean, and in Africa where cowpea originated and was domesticated.

Through collaborative research projects, scientists discover new genetic sources for yield-enhancing traits, early maturation, disease and insect resistances, drought and heat tolerances, high biological nitrogen fixation, grain quality traits required by markets, high nutritional content and improved processing and culinary attributes (Table 1, page 11 and Table 3, page 19). The following are examples of genetic improvement research achievements by LIL scientists that benefit the U.S. grain legume industry.

| New Genes Sourced |

- Common bean – New genetic sources of resistance to economically important diseases (anthracnose, angular leaf spot, common bacterial blight, rust, Bean Common Mosaic Virus), and insect grain storage pests (weevils) have been identified and bred into varieties.
- Meso-American Climbing Beans – DNA analyses on an under-exploited bean germplasm collection reveals a potential source of new genes for low temperature tolerance, disease resistances and agronomic traits.
- Cowpea – Genes for lugus bug tolerance, and root-knot nematode and Fusarium wilt resistances have been combined in new improved varieties of cowpea for production in California and the U.S. Southwest.
- Tepary bean (*Phaseolus accutifolius*) – A species of *Phaseolus* with adaptation to high temperatures and drought is being genetically improved for grain size, disease resistances and agronomic traits. The new Tepary bean varieties will provide farmers in the Southern US that are vulnerable to frequent droughts and high temperatures with an alternative adapted bean crop.

| Varietal Releases |

- New upright high yielding black bean varieties, 'Zorro' and 'Zenith', developed with Dry Grain Pulses CRSP support by the bean breeding program (Dr. James Kelly, PI) at Michigan State University are now the primary varieties grown in Michigan, the largest black bean producing state in the U.S. The economic value to growers by these varieties, based on a 10% yield increase, is estimated at >$10 million per year.

- The high yielding blackeye pea (cowpea) variety 'UB46' which dominates the production acreage in California and Texas was bred by scientists at the University of California-Riverside with support from the DGP CRSP. New varieties (07KN-74, CB46Rk2) with additional resistance traits are being bred for release with support from the LIL.

| Evidence of Breeding Impact on Varietal Improvement in the U.S. |

- As a result of USAID's long-term support of the bean breeding program at Michigan State University (MSU), a total of 29 varieties representing 10 different common bean market classes with one or more parents from the MSU program are being commercially grown in Michigan. At the national level, 40 commercially produced varieties of common bean have MSU parentage.

B. Strengthened Research Capacity in Grain Legumes at U.S. Universities

U.S. University Commitment to Grain Legume Research Positions: Due to the long-term commitment of USAIDs' Bureau for Food Security to support grain legume research through such programs as the DGP CRSP and LIL, the administrations of U.S. universities have made strategic faculty hires to build multidisciplinary research capacity to support the grain legume industries in their respective states and regions and to enhance the international engagement of their faculty. In addition, the DGP CRSP and LIL have supported the cowpea breeder position at the University of California-Riverside.

Collaboration by U.S. University Scientists with Peer Scientists around the World: Through DGP CRSP and LIL projects, U.S. university grain legume scientists are able to network and collaborate with leading international scientists who share common research interests. These include research scientists working in diverse disciplines with complementary expertise affiliated with National Agriculture Research Organizations, agricultural universities and selected International Agriculture Research Centers engaged in grain legume research (e.g., CIAT, IITA, ICRISAT, IFPRI, etc.). These collaborations allow them to conduct specific types of research (i.e., phenotyping, field trials in unique environments or with exposures to disease and insect pressure, nutrition and food intervention studies, market analyses, etc.) that would be difficult to conduct in the U.S. Such research accelerates technical progress for the benefit of the U.S. grain legume industry.

Access to top International Graduate Students: The DGP CRSP and LIL support graduate students from FTF countries with high academic potential to pursue graduate degrees at U.S. universities and conduct thesis research projects that generate new knowledge and contribute to the development of technologies directly benefiting the U.S. grain legume industry. As an example, the "Legume Scholars Program" supports the PhD programs of five elite African students at five U.S. universities. These students are conducting innovative research on grain legumes in such areas as consumer preferences, genomics, plant physiology, soil fertility management, and food science.

2. Benefits to the U.S. Dry Bean Industry

State and national dry bean industry associations in the U.S. (Michigan Bean Commission, US Dry Bean Council, American Pulse Association), comprised of growers, grain traders and processors of grain legumes, have been strong supporters of the DGP CRSP and LIL because of research outputs and specific initiatives that have directly contributed to the growth and future viability of the bean industry.

Leadership in Human Nutrition Research: Through a partnership between the USDBC and the Bean/Cowpea CRSP, a Global Development Alliance (GDA) Grant from USAID was awarded (2004-2006) that financed human nutrition research and education on beans in the U.S. and abroad. The 'Beans for Health Alliance' (a 501(c)(6)) and the "Beans for a Healthy Heart" educational campaigns had their beginnings under this GDA which shifted the industry focus from increasing production to promoting the nutritional and health value of nutrient-dense bean-based foods.

The DGP CRSP and LIL continued to play a leadership role in grain legume nutrition and health research that is highly valued by the U.S. bean industry.

A. *Bioactive compounds in cowpea:* A study lead by Texas A&M (Dr. Joseph Awika, lead PI) in partnership with institutions Kenya, Zambia, and South Africa, found that light brown cowpea varieties have high tannin content while red varieties contained most flavonoids. High tannin composition was correlated with strong oxidative stress inhibition, while high flavonoid and anthocyanin composition correlated with prevention of chronic inflammation.

b. Gut health and child growth: A study lead by Washington University in St. Louis (Dr. Mark Manary, lead PI) conducted a large food intervention study involving >600 infants (6 months to 2 years) in Malawi to investigate the effects of supplemental bean or cowpea based supplemental foods on infant growth, the bacterial ecology of the gut microbiome and biomarkers of gut health. (See D.1 for findings)

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> The findings from these landmark nutrition studies (by the DGP CRSP and LIL) will inform the design of nutrition education programs and food product labeling by food industry groups, and potentially dietary policy in the U.S.

Enhanced Understanding of Foreign Bean Markets: Through DGP CRSP and LIL research in FTF developing countries in Africa and Latin America, new understandings are gained regarding consumer preferences and demand for value-added bean and cowpea food products, especially by urban populations. This information is valuable to U.S. industry groups since approximately 40% of U.S. produced beans are exported.

In addition, an ISU led DGP CRSP study with Makerere University in Uganda developed nutrient-enhanced and shelf-stable bean-based food products (flours, pastries, pasta, etc.) that have culinary and sensory characteristics preferred by consumers. These nutritious products are being processed and marketed in Eastern Africa, thus creating possible shelf space for other bean based food products.

2016 International Year of Pulses (IYP): In celebration of the Food and Agriculture Organization's declaration of 2016 as the "International Year of Pulses", the LIL Management Office at Michigan State University and LIL scientists partnered with both domestic (American Pulse Association, US Dry Pea and Lentil Council, US Dry Bean Council) and international grain legume industry groups (e.g., Global Pulse Confederation, Emerging-ag Inc.) to develop white papers, educational messages and a 10-year research strategy for grain legumes (pulses). These were used to inform congressional representatives as well as consumer groups in both the U.S. and countries around the world about the importance of pulses to food security, cropping system sustainability, economic vitality of agribusinesses, and human health and nutrition.

In addition to participation in numerous IYP promotional events in Michigan, the Legume Innovation Lab Management Office at Michigan State University assumed a leadership role in organizing and hosting the "PanAfrican Grain Legume Research Conference and World Cowpea Conference" in partnership with the International Institute for Tropical Agriculture (IITA) in Zambia in March 2016. Identified by the FAO as one of 10 signature international events to celebrate IYP, the conference was attended by 550 scientists and industry leaders from 46 countries including a strong delegation of U.S. scientists and private industry representatives.

Little Beans, Big Opportunities Symposium, Sackler Institute for Nutrition Science (New York Academy of Sciences), NYC, November 2015: A symposium was jointly organized and convened by Pulse Canada, the Legume Innovation Lab, and U.S. grain legume processing companies to launch the *International Year for Pulses* in North America. An outcome of this symposium was the publication of "Global Pulses Scenario: Status and Outlook" in the Annals for the New York Academy of Science.

2017 BIFAD Award for Scientific Excellence to LIL PIs Drs. James Beaver and Juan Carlos Rosas {F3}

Dr. James Beaver, of the University of Puerto Rico, and Dr. Juan Carlos Rosas, of the Escuela Agricola Panamericana-Zamorano in Honduras, were selected as winners of the 2017 Board of International Food and Agriculture Development (BIFAD) Award for Scientific Excellence in a Feed the Future Innovation Lab.

They were recognized for their contributions to breeding disease resistant and drought tolerant/heat tolerant varieties of common bean of diverse market classes under the Feed the Future Innovation Lab for Collaborative Research on Grain Legumes, led by Michigan State University. Drs. Beaver and Rosas were PIs for the project entitled *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.*

The team is responsible for the breeding and release of more than 60 cultivars of common bean with increased yield, quality, and stability throughout Central American and Caribbean countries. They developed more than 23 bean lines and germplasm resistant to Bean Golden Yellow Mosaic Virus, Bean Common Mosaic Virus, and Bean Common Mosaic Necrosis Virus- three highly destructive bean viruses within the region that dramatically reduce bean yields on vulnerable smallholder farms (Table 1, page 11 and Table 2, page 15).

Drs. Beaver and Rosas are also recognized for combining other important traits into the virus-resistant bean cultivars, including resistance to fungal diseases, such as web blight and angular leaf spot, and to bean weevil, a serious postharvest grain pest during household storage, plus higher symbiotic nitrogen fixation capacity. Additional research achievements have been genetic improvements in heat and drought tolerance in common bean, which has enabled production in the lowland tropics. This work has been augmented by recent support from the Feed the Future Innovation Lab for Climate-Resilient Beans, led by Pennsylvania State University. Their research collaboration spans more than 30 years beginning under the Bean/Cowpea CRSP and continuing through the Dry Grain Pulses CRSP (2007-2012) and the Legume Innovation Lab (2013-2017). The technological outputs of their research have contributed directly to improved incomes and increased food security among smallholder farmers in a neglected region of the world.

Drs. Beaver and Rosas have also provided innovative leadership in developing and promoting local seed multiplication systems to ensure that smallholders have access to quality bean seed of improved varieties. Using participatory plant breeding approaches, they have effectively used smallholder farmers' input in making varietal selections– an approach now used worldwide in crop improvement (Table 2, page 15).

Always focused on the future of bean research, Beaver and Rosas are committed teachers and have trained and mentored a large cadre of students who are now working in leadership positions at universities, national/international agriculture research organizations and the private sector around the world.

This recognition by BIFAD of two PIs brings high international distinction to the FTF Legume Innovation Lab program for its unparalleled scientific quality, technical

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performance and the contributions of research outputs to development outcomes within FTF countries.

The Board for International Food and Agriculture Development (BIFAD) is a presidentially appointed federal advisory committee established in 1975 under Title XII of the Foreign Assistance Act, as amended. Recognizing the critical role of U.S. land-grant institutions in agriculture development, domestically and abroad, and the importance of their engagement in USAID development programs, the BIFAD's main purpose is to advise USAID on agriculture and higher education issues pertinent to global food security in developing countries. For questions, please contact the Designated Federal Officer for BIFAD, Dr. Clara Cohen, at ccohen@usaid.gov or 202-712-0119.

Communicating Scholarly Achievements in Grain Legume Research {F4}

The performance of a research program is best measured by the quality and quantity of scholarly scientific communications documenting newly generated technologies and knowledge that are made publically available by investigators to international communities of peer researchers, industry groups, development professionals, public sector institutions, and other interested groups.

Scientists and graduate students involved in the Dry Grain Pulses CRSP and Legume Innovation Lab program utilized diverse communication instruments to share their research achievements. Complete Bibliographies of Publications for both the DGP CRSP (2007-2012) and LIL (2013-2017) appear in Appendix 3 and 4. The Bibliography of LIL publications is organized by Strategic Objectives and includes scientific articles in refereed journals, book chapters, and other outputs (technical reports, conference papers, working papers, manuals, etc.)

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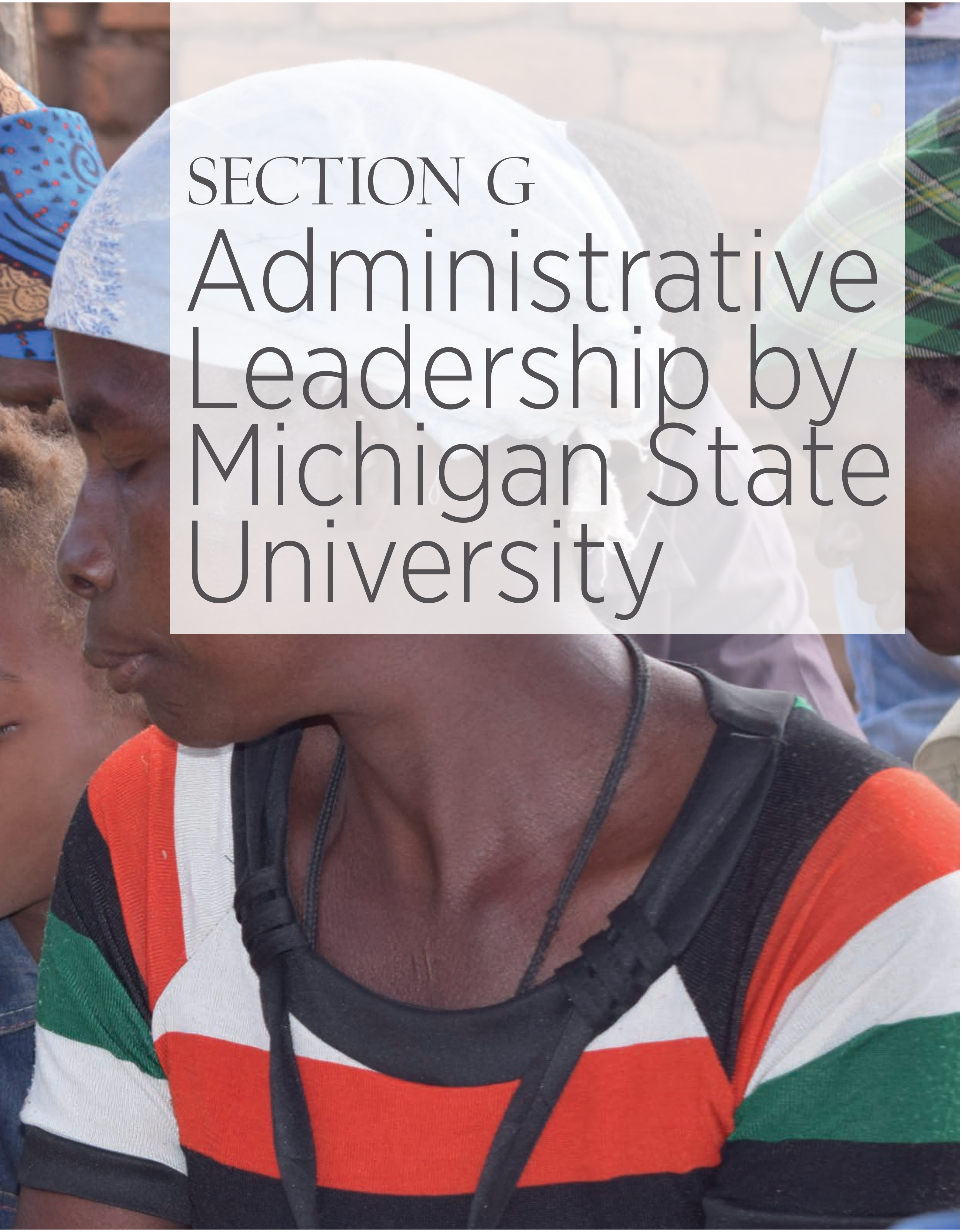
The scholarship and productivity by U.S. and host country scientists participating in the DGP CRSP and LIL, as evidenced by the extensive list of research papers in refereed scientific publications, are extremely impressive. Since these articles were reviewed and recommended for publication by knowledgeable peer scientists, a reader can have confidence in the quality of the scientific methods, analyses and interpretation of the results from the research.

A reading of the bibliography reveals that the overwhelming majority of journal articles included collaborating host country (HC) scientists as senior and co-authors. This demonstrates the commitment by DGP CRSP and LIL PIs to collaborative research, to mentorship, and to enabling HC scientists to assume intellectual leadership in research and ownership of the research achievements.

It is also noteworthy that DGP CRSP and LIL scientists utilized the platform of scientific conferences to present their research findings, especially scientific meetings within the FTF focus regions (i.e., annual PCCMCA meeting in Central America, Conference of the African Association of Insect Scientists, etc.) and the biennial grain legume research conferences organized by the Management Office at Michigan State University. These scientific meetings attracted a multidisciplinary group of participants with whom PIs and graduate students could obtain critical feedback from peers, learn new ideas and research approaches, network and consider innovative collaborative research for the future.



SECTION G
Administrative Leadership by Michigan State University

The Management Office's Technical Leadership of the DPG CRSP and LIL Program – Staying Ahead of the Innovation Curve {G1}

The Management Office (MO) of the Dry Grain Pulses Collaborative Research Support Program (DGP CRSP) and the Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (Legume Innovation Lab- LIL) was tasked with providing technical and administrative leadership to the program, according to USAID's contract with Michigan State University, the management entity (ME). It is relatively easy to understand and appreciate the administrative leadership responsibilities associated with the contractual and financial management of a complex federal USAID research and training program. The technical leadership roles of the Management Office at Michigan State University are perhaps less obvious to an outsider.

The simplest way to think about the possible technical roles of the Management Office is to view the Legume Innovation Lab as an international "competitively awarded" research program that focuses on developing public goods (technologies and new knowledge) involving grain legumes (e.g., common bean, cowpea, etc.) to achieve development outcomes.

Since USAID is not fundamentally a science agency within the federal government, but a development and relief agency, USAID, in accordance with Title XII, contracts Innovation Lab programs to U.S. universities with predominant capacity in strategic areas of science critical for the implementation of the program. Predominant capacity is evidenced by the provision of qualified "key" personnel by the ME university, including the Director and Deputy Director, plus university research faculty with relevant scientific expertise and international experience.

In the case of the DGP CRSP and LIL program, Dr. Irvin Widders, Director, Professor of plant physiology with extensive international agriculture research and development experience in Central and South America, provided technical leadership in the areas of biological and physical sciences. He was complemented by Dr. Cynthia Donovan, Deputy Director, Associate Professor of agriculture economics with long-term professional experience in Western and Southern Africa. Dr. Mywish Maredia, Professor of Agriculture Economics, served as Deputy Director of the DGP CRSP from 2007-2010 and contributed significantly to the program in the area of impact assessment of research. Having multidisciplinary leadership in the MO was important for the development and implementation of an innovative and effective program that would achieve FtF's research for development goals.

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Looking back over the past ten years of the program (2007-2017), the following are evidences of innovations in technical leadership by the Management Office.

1. Formulation of a robust technical vision

An innovative and vibrant technical research vision was formulated for the DGP CRSP and LIL program. The technical vision aligned with the U.S. government's Initiative to End Hunger in Africa (IEHA) (2007-2009) and Feed the Future (FTF) (2010-2017) and responded to formidable challenges and opportunities facing the various sectors in bean and cowpea value chains extending from smallholder farmers to consumers.

The DGP CRSP technical vision (see Section A.1) was based on an assessment of (1) Trends and Critical Issues, (2) Roles of Pulses/Grain Legumes in Africa and Latin America, and (4) Emerging Issues. Salient issues considered included limited gains in grain legume productivity and profitability of smallholder farms, recalcitrant production problems, the persistent Nutritional Gap and opportunities to improve nutritional security through nutrient-rich grain legumes, and weak grain legume value-chains with limited private sector investment.

The LIL technical vision was based upon the need: (1) to build upon the technical advances achieved under and lessons learned from the DGP CRSP (2007-2012); (2) to effectively utilize innovative research approaches afforded by modern science and capacities of U.S. universities; and (3) to propel the LIL scientific community into a position of international leadership in bean and cowpea research.

2. Utilizing external technical advice

The development of a quality coherent portfolio of research projects that engages the best multidisciplinary teams of U.S. and host country scientists to achieve the strategic objectives of the program is perhaps the most important task of the Management Office. The MO has been convinced that research hypotheses and approaches do matter in solving problems and that the most innovative ideas emerge through a competitive process of soliciting, peer review and selection of proposals to fund. The process of developing and managing a portfolio of research projects, however, greatly benefits from advice from external scientists experienced in agriculture research program administration.

The MO for the DGP CRSP and LIL demonstrated technical leadership by establishing and using two external advisory bodies.

a. *External Advisory Panel (EAP)* – EAPs were convened ad-hoc to advise the MO in the selection of peer-reviewed proposals received in response to the solicitation of Requests for Proposals. Since the EAP members were external without conflicts of interest, had technical expertise in areas where the MO was weak, plus extensive knowledge of international agriculture development issues, consultations with EAPs were found to be incredibly valuable when constituting a multi-faceted research program with collaborating scientists and institutions from throughout Africa, Central America and the Caribbean.

b. *Technical Management Advisory Committee (TMAC)* – The TMAC was an external advisory panel established to perform both strategic planning and both technical and administrative management and monitoring functions. This is a novel committee that was envisioned by the MO at MSU to achieve administrative economies and efficiency, ensure accountability, and receive the best objective expert advice possible for administration of the program. (See article G.5 for more details on TMAC)

3. Identifying emerging areas of science and recruiting a new generation of PIs

The Management Office is proud of its technical success in identifying emerging cutting-edge areas of science and research approaches to accelerate technological advances to bring game-changing benefits to smallholder grain legume farmers. Success was also achieved in recruiting a new generation of scientists to the program who could apply their unique skill sets with modern science to address legume problems in developing country contexts. Examples of such successes include:

- Use of biocontrols and IPM-omics to sustainably manage insect pests in cowpea; Dr. Barry Pittendrigh, Lead PI, Michigan State University (see article B.5)
- Improving gut health, nutrition and growth of young children, Dr. Mark Manary, Lead PI, Washington University in St.Louis (see article D.1)
- Phenotyping of photosynthetic traits, Dr. David Kramer, Lead PI, Michigan State University (see article B.2)
- Genomics and novel gene exploration in under-exploited climbing bean germplasm, Drs. Juan Osorno, Lead PI, and Phil McClean, North Dakota State University (see articles B.6 and B.2)
- Mapping of smallholder farm landscapes to improve soil fertility management decision-making, Drs. Robert Mazur, Lead PI, Lee Burras and Bradley Miller, Iowa State University (see article C.3)

4. Strategic partnerships

For a program of the stature of the DGP CRSP and LIL to be relevant, to exert international leadership and to achieve developmental impact, it is imperative that it be connected to and partner with other leading international public and private institutions with a shared interest and commitment to grain legume research. Over the past 10 years, the MO has made a concerted effort to engage and coordinate research and institutional capacity strengthening efforts with the following institutions.

a. *USDA/ARS* – USDA/ARS common bean geneticists, Drs. Tim Porch (TARS, Puerto Rico), Phil Miklas (Prosser, Washington) and Karen Cichy (MSU), actively collaborated in and received financial support through several LIL projects, thus fulfilling the all-of-government mandate of Feed the Future.

b. *IITA, CIAT and CGIAR Consortium Research Program on Grain Legumes* – The LIL and DGP CRSP program had both direct and indirect collaborations with the grain legume research programs of the CGIAR. Dr.

Manuele Tamo, IITA-Benin, served as a Co-PI on the research project to develop biocontrols for insect pests in cowpea. Irv Widders, Director, served on the Research Management Committee of the CG's Grain Legume CRP administered by ICRISAT. In a reciprocal manner, CG scientists Steve Beebe, Robin Burachara, Ousmane Bukar and Noel Ellis (Director GL CRP) served on the TMAC of the DGP CRSP and LIL. This facilitated communication, collaboration and coordination of research activities among the various grain legume research projects supported by USAID to ensure complementarity and synergies.

> The MO enjoyed excellent communication with and advocacy support from state, national and international private bean/ pulse industry groups.

c. *Michigan Bean Commission (MBC), US Dry Bean Council (USDBC), American Pulse Association (APA) and the Global Pulse Confederation (GPC)* – The MO enjoyed excellent communication with and advocacy support from state, national and international private bean/pulse industry groups. Greg Varner represented the interests of the MBC and the USDBC on the TMAC. Irv Widders was periodically invited to USDBC board meetings to inform them of DGP CRSP and LIL research activities and achievements of interest, especially as related to health and nutrition. For the 2016 International Year of Pulses, the Global Pulse Confederation through Emerging-ag Inc. invited Irv Widders to serve on two strategic IYP planning committees, the Sustainability and Productivity and the Nutrition/Health Committees. These industry groups also partnered with the LIL to sponsor the Sackler Institute symposium on "Little Beans, Big Opportunities: Realizing the Potential of Pulses to Meet Today's Global Health Challenges" on November 19, 2015 in NY.

The legacy on innovative technical leadership exemplified in the DGP CRSP and LIL Management Office will hopefully serve as a model for future Innovation Lab programs.

Fostering Innovation and Transformation through Research Collaboration and Networking {G2}

A fundamental premise of Dry Grain Pulses CRSP and the Legume Innovation Lab has been that collaborative research and networking by scientists lead to innovation and meaningful transformation of grain legume value chains in developing countries. The strong professional relationships that were forged between U.S. university and host country (HC) grain legume scientists through this program gave rise to innovative technologies and new knowledge that will leave an indelible imprint on the growth and vitality of the grain legume value chain sectors and the livelihoods of smallholder grain legume farmers in Feed the Future countries and the U.S. The scholarly research achievements and impacts of the DGP CRSP and LIL are highlighted in this Ten-Year Legacy Report.

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At the inception of each competitively awarded project, the Management Office established an expectation that principles and guidelines for "collaboration" be adhered to and implemented by the projects. The collaborative partnering relationships and the roles of individual scientists were defined in the subcontracts, annual workplans and budgets with participating institutions in each project. The Technical Management Advisory Committee of the DGP CRSP and LIL then annually assessed both collaborative team dynamics and performance by each project.

Salient values and guidelines for "collaboration" that were considered important for success of research projects in the DGP CRSP and LIL included:

1. Selection of committed partner institutions and scientists: It was incumbent on the Lead PI to select collaborating scientists and institutions who were committed to achieving the research output objectives and long-term developmental outcomes in the target Feed the Future countries and regions. It was critical that HC scientists be identified who had the desired research skills, demonstrated potential to grow and mature as scientists, exhibited scientific integrity, were open to new ideas and approaches, and were passionate about improving the grain legume productivity and the livelihoods of smallholder farmers through their research and outreach activities.

2. Mutually beneficial: Collaborative research needed to be mutually beneficial to both U.S. and HC scientists in spite of the fact that each team member would have different roles and assigned research tasks. Division of research responsibilities took advantage of the expertise and capacities of each scientist and laboratory/institutions and maximized benefit to the scientists and their respective institutional research programs on grain legumes.

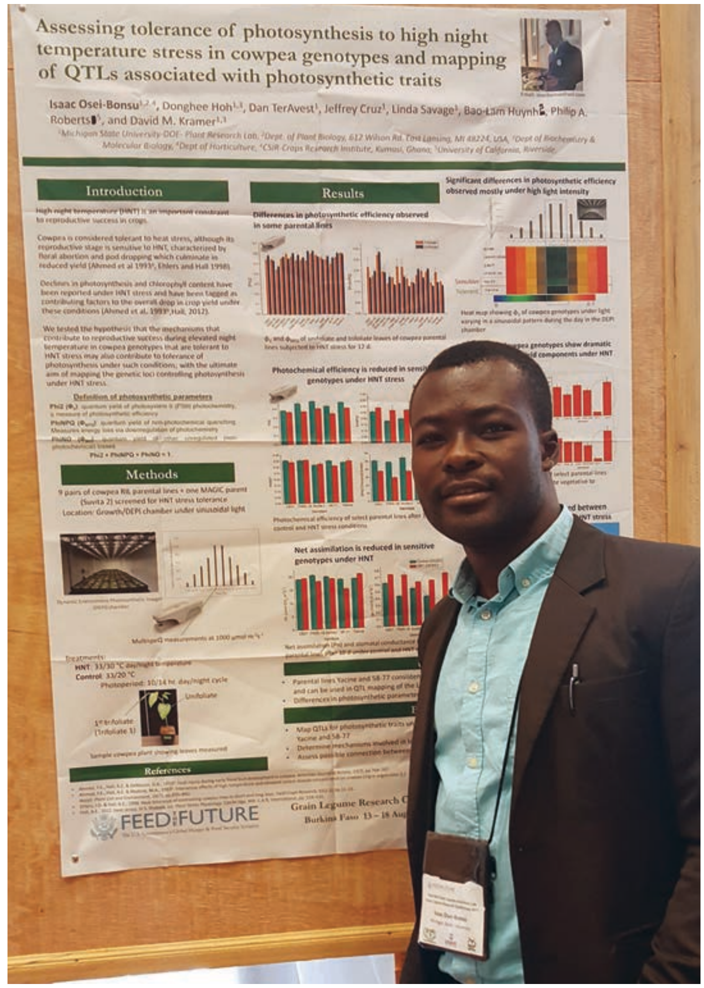
3. Mutual respect: Collaborating scientists and institutions regarded one another as professional peers and equals in all dealings. As peers working toward common research goals, each partner treated team members with respect, expected excellence, was transparent and effectively communicated, and fulfilled designated research commitments in a coordinated manner so as to make necessary technical progress toward objectives.

4. Mutual learning: Research involves the testing of hypotheses, discovery of new knowledge, and the development of novel technologies. Regardless of whether a team member is a U.S. or host country scientist, or a mature scientist or graduate student, researchers were willing to learn from one another. Host country scientists best understood the agro-ecologies and the socio-economic factors that might constrain grain legume production and markets in a Feed the Future country. Likewise, graduate students and fundamental U.S. university scientists brought knowledge of cutting-edge areas of science that contributed to major gains in technology development (e.g., genomic tools in varietal development).

5. Appropriate budgeting of project resources: Effective collaboration requires sharing of funds between host country and U.S. institutions to effectively complete research activities. Within the DGP CRSP and LIL projects, host country institutions were required to receive a minimum of 50% of direct funds for research and training. The Management Office recognized though that when three or four scientists/institutions collaborated in a project, funding for any one institution was less. The combination of appropriate budgeting and the leveraging of funds from other grant sources, however, enabled projects to complete their research responsibilities.

6. Shared ownership and accountability: The success of collaborative research projects was dependent on all partners working together toward common goals. Accordingly, partners shared ownership of the project, gave due attribution for individual successes and achievements and held each other accountable for delivery on commitments.

Scientific exchange of findings and ideas plus networking among peers and across disciplines played an equally vital role in the use of new research approaches and the development of innovative new technologies as collaboration within DGP CRSP and LIL project teams. The challenge faced by many developing country grain legume scientists was that they had limited opportunity to interact with other grain legume scientists in their home institution or country. Within National Agriculture



Research Organizations (NAROs) the number of researchers working on beans and cowpeas was typically low and few professional agricultural societies exist in Africa and Latin America that provide fora for research sharing and scientific exchange on grain legumes.

To facilitate scientific exchange and networking, the DGP CRSP and LIL Management Office organized biennial conferences that brought together PIs, collaborating CGIAR scientists, graduate student trainees and specially invited speakers. During each conference, oral and poster sessions provided opportunity for PIs to present research findings and achievements, and to learn from discussions on critical topics of interest such as increasing grain legume productivity, improving resistance to abiotic stresses, sustainable seed systems, improving farmer integrated crop management decision-making, growing markets for grain legumes, and human nutrition. Highlights of the conference were the field visits that enabled participants to observe bean or cowpea production and to interact with local smallholder farmers in the host country.

Convened conferences that are part of the DGP CRSP and LIL's legacy include:

2009 First Dry Grain Pulses CRSP PI Conference, Barcelona, Spain

2010 Dry Grain Pulses CRSP All Researchers Conference, Quito, Ecuador

2012 Dry Grain Pulses CRSP Research Conference, Kigali, Rwanda

2014 Legume Innovation Lab Research Conference, Athens, Greece

2016 Joint PanAfrican Grain Legume Research Conference and World Cowpea Conference, Livingstone, Zambia

2017 LIL Grain Legume Research Conference, Ouagadougou, Burkina Faso

Lessons learned by the Management Office from organizing these conferences.

1. PIs need time during the conferences to meet and coordinate research activities with their respective project teams.

2. Attending sessions of scientists working in other disciplinary areas or on distinct grain legume constraints was of great value to many developing country scientists.

3. Grain legume research conferences provided opportunity for early career scientists and graduate students to gain public speaking experience, to meet internationally recognized grain legume scientists for the first time, and to establish networks for future interaction.

4. The experience of host country PIs from Africa and Latin America to visit a different continent or region, to learn of the constraints confronting smallholder bean and cowpea farmers, and to share with other scientists who face similar research challenges was enlightening and many times transformative.

Joint PanAfrican African Grain Legume and World Cowpea Conference

During the week of February 28 to March 4, 2016, the joint PanAfrican Grain Legume and World Cowpea Conference was held in Livingstone, Zambia. This was the first continent-wide scientific conference in Africa that focused on grain legumes. (http://gl2016confa.iita.org/)

The Feed the Future Legume Innovation Lab (LIL), administered by Michigan State University, took the leadership in organizing this strategic conference in partnership with the International Institute for Tropical Agriculture (IITA), the Centro Internacional de Agricultura Tropical (CIAT), the Zambia Ministry of Agriculture and CCARDESA.

The United Nations Food and Agriculture Organization (FAO) identified the PanAfrican Grain Legume and World Cowpea Conference as the sole signature international event in Africa to celebrate the 2016 International Year of Pulses (http://www.fao.org/pulses-2016/en/).

The International Year of Pulses was established in recognition of the importance of edible grain legumes (e.g., beans, cowpeas, pigeonpea, and chickpea) to improving the livelihoods of rural farmers especially women, human health and nutrition, and the sustainability and productivity of agriculture systems worldwide.

The landmark conference attracted approximately 550 participants from 46 countries throughout Sub-Saharan Africa, Latin America, the United States and India. The conference program included eight thematic plenary sessions with invited guest speakers, approximately 500 presentations of scientific research papers in sixteen oral and two poster sessions, and a Technology Marketplace Exhibition.

Honored dignitaries who participated in the PanAfrican Grain Legume Conference included the Zambian Minister of Agriculture and

Livestock, the Executive Director of the Forum for Agriculture Research in Africa (FARA), the Executive Director for CCARDESA, the Chief Scientist of USAID, the Director Generals from three International Agriculture Research Centers (IITA, CIAT, ICRISAT), a Project Officer from the Bill and Melinda Gates Foundation, the Executive Secretary from the Global Pulse Confederation, and the Director of MSU AgBioResearch.

A follow up survey of conference attendees revealed that researchers placed high value on face-to-face meetings for networking and possible future collaboration, benefitted from interactions with multidisciplinary sets of participants and presentations focusing on diverse constraints and grain legume commodities, and learned the importance of designing research projects to achieve impacts and cross-cutting develop outcomes in gender equity, nutritional security and youth empowerment. One respondent to the survey stated: “The conference was a great learning event for me. As a young educator and researcher, I feel energized to continue my grain legume research efforts for the betterment of Africa and the world.”

The Legume Innovation Lab is grateful to the numerous private and public sector organizations for their financial support of the conference, including: the U.S. Agency for International Development (USAID), Michigan State University, the Bill and Melinda Gates Foundation, Archer Daniels Midland Edible Bean Specialties Inc., the McKnight Foundation, the Kirkhouse Trust, AGRA, and IITA. A special thanks goes to the Crop Science Society of America (and President Elect Dr. Michael Grusak) for its provision of the CONFEX system to facilitate the electronic submission of abstracts and preparation of the scientific program for the conference.

5. Participation by CGIAR scientists in the conferences encouraged greater scientific exchange and coordination of research activities with HC and US PIs participating in the DGP CRSP and LIL.

6. The international multidisciplinary community of grain legume scientists that was formed through the program over the past ten years will continue and be a foundation for future collaborations after the Legume Innovation Lab ends.

It is noteworthy that the DGP CRSP and LIL PIs also played leadership roles in other grain legume research communities including the Bean Improvement Cooperative (BIC) and the PCCMCA (Programa Cooperativa CentroAmericana de Mejoramiento de Cultivos y Animales). In 2015, the LIL partnered with ICTA-Guatemala to organize a special symposium on research advances in common bean for the PCCMCA meeting in Guatemala City.

The international stature of DGP CRSP and LIL was evident when it partnered with the International Institute for Tropical Agriculture (IITA) to cohost the World Cowpea Conferences in Saly, Senegal (2010) and in Livingston, Zambia (2016). The conference in Zambia was held in conjunction with the PanAfrican Grain Legume Conference which celebrated the 2016 International Year of Pulses (see Box 1). PIs, collaborators and graduate students from the DGP CRSP and LIL played prominent leadership roles in these World Cowpea Conferences through presentations of their research achievements and organizing teams of regional cowpea scientists to focus of specific challenges facing smallholder cowpea

Why Social Science Research is Strategically Important for Achieving Sustainable Impact {G3}

Social science research seeks to understand human behavior and how humans interact with their physical and institutional environments. The leadership of the Dry Grain Pulses CRSP and the Legume Innovation Lab believe that an understanding of human behavioral dynamics is vitally important to the development of technologies and management practices that will be adopted and contribute to sustainable increases in grain legume productivity by smallholder farming systems, and improved performance of grain legume value chains. For this reason, the program made a commitment to supporting multidisciplinary research projects that integrated social science research components.

> An understanding of human behavioral dynamics is vitally important to the development of technologies and management practices that will be adopted and contribute to sustainable increases in grain legume productivity by smallholder farming systems, and improved performance of grain legume value chains.

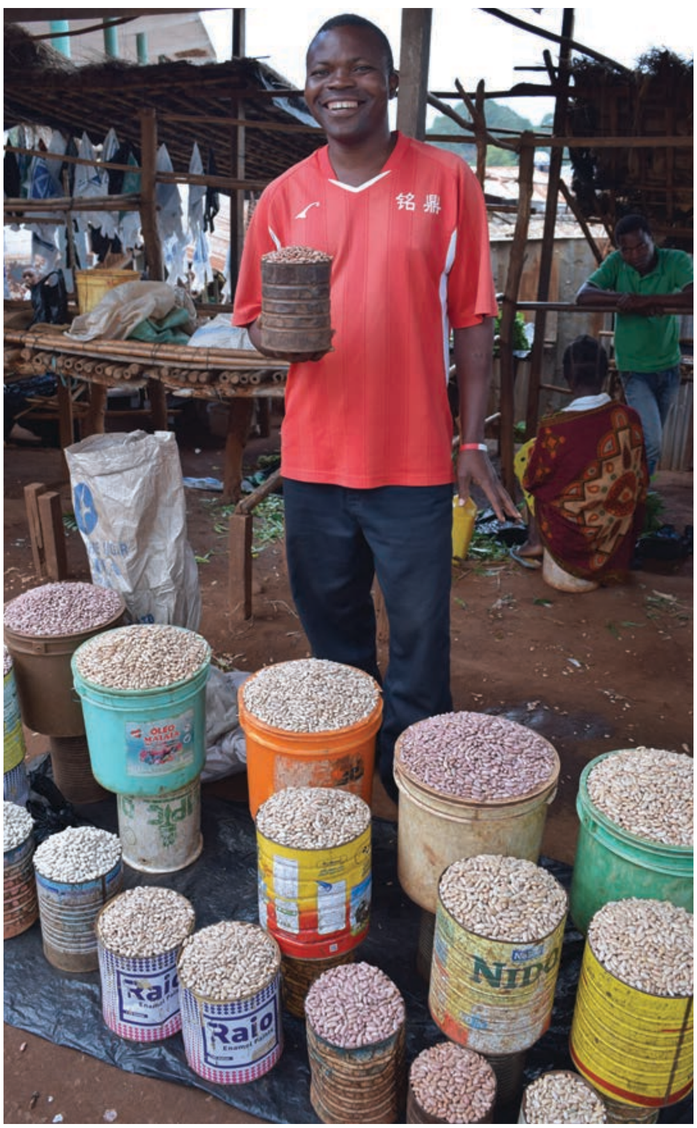
Within the portfolios of DGP CRSP and LIL research program, social science research has provided insights into farmer decision making, value chain organization, governance and function, the adoption and diffusion of technology, factors affecting impact, the efficacy of learning tools and methods, and the sustainability of technological change. LIL scientists (e.g., plant breeders, agronomists, soil scientists, entomologists, food scientists and even nutritionists) have come to discover the value of knowledge generated by social science research and its relevance to biophysical science research. Without such insights, LIL research outputs may not be embraced and utilized by end-users in grain legume value chains (i.e., women farmers, resource poor farmers, household dietary decision makers, traders, urban consumers, etc.) because of socio economic factors that were not understood or appreciated.

The following are examples where social science research played an important role in the design and dissemination of a technology or management practice within the DGP CRSP and LIL program. The expected benefits from socio-economic research are the incorporation of demands into technology development, improved efficacy and adoption of the research outputs, and increased sustainability of the development outcomes to the grain legume sectors.

Although input technologies such as seed of disease resistant high yielding varieties, fertilizers and pesticides increase bean and cowpea yields, smallholder resource poor farmers have specific reasons for deciding whether to invest or not in an input. This fact became evident from studies conducted by Dr. Mywish Maredia (MSU) in Nicaragua, Tanzania, Burkina Faso and Ghana that assessed smallholder farmer 'willingness to pay' (WTP) for certified or Quality Declared Seed (QDS) of improved varieties of bean and cowpea. Although bidding auction experiments in Nicaragua revealed that 30-35% of farmers were willing to pay a price premium for quality bean seed, significantly above the price of certified seed, the reality is that many fewer farmers purchased and planted certified or QDS seed than would be expected. This finding suggests that poorly understood socio-economic factors may be contributing to the low apparent smallholder farmer demand for quality seed including a lack of trust of seed suppliers (inferior seed quality, mislabeling of varieties) or supply-side constraints. Future research is therefore needed to find ways to reduce the costs of grain legume seed production, certification and delivery while improving seed quality guarantees so as to increase demand of seed of improved varieties of bean and cowpea.

The development of diagnostic and decision support tools to aid smallholder farmers in making better integrated crop management decisions to increase bean productivity and sustainably improve soil fertility also required social science research. ISU rural sociologist Dr. Robert Mazur led a team in Uganda and Mozambique that worked with farmer groups and members of multi-stakeholder bean value chain innovation platforms. By establishing community based trials and demonstration sites, the social scientists were able to engage farmers in the field to evaluate promising soil and bean crop management practices and learn about critical social, economic, and cultural factors that influence their decision making. Social scientists also enabled soil scientists to better understand farmer soil classification systems and indigenous knowledge regarding soil health and management. These insights led to the joint development of innovative communication and dissemination strategies that integrated multimedia, including SAWBO animations delivered via smartphones, soil management guides designed for low education learners, and computer apps on bean production to be used by agriculture extension specialists.

Understanding consumer preferences, which drive consumer demand for diverse market classes of beans (e.g., small red, cranberry, pinto, canary, kabulangeti) and cowpeas and of value-added products, are best investigated by multidisciplinary teams led by socio-economists. KSU agricultural economist, Dr. Vincent Amanor-Boadu in collaboration with socio-economists at UNZA, LUANAR and SUA, conducted consumer surveys to determine farmer and consumer needs and preferences for bean market classes, processed products and culinary quality attributes (cooking time, broth quality, texture, flavor and nutritional quality) in Zambia, Malawi and Tanzania. This information is vitally important to bean breeders for setting objectives and protocols for varietal development for target regions and markets. Actors in bean and cowpea value chains, especially processors, also gain from the insights of socio-economic research when planning future production and value-addition to respond to anticipated consumer demand.



> The inclusion of legume crops in a cropping system either as a rotation crop or inter-crop positively influenced indicators of household income, food security, dietary diversity and calorie and protein production . . . has major policy implications for FTF countries facing food and nutritional security challenges.

Farmer choices of technology, especially the use of legume-based cropping practices, were shown by Dr. Mywish Maredia, to have a significant effect on food production and nutrient production from case studies in Uganda and Zambia. The inclusion of legume crops in a cropping system either as a rotation crop or inter-crop positively influenced indicators of household income, productivity, food security, dietary diversity as well as calorie and protein production by the farm system. It was estimated that the addition of one hectare of land cultivated in cereal/legume rotation would give rise to an 18 percent increase in per capita daily calorie production, from 5,913 to 7000 calories/capita/day. Findings such as these have major policy implications for FTF countries facing food and nutritional security challenges.

Unquestionably, socio-economic research not only added value to and enhanced the efficacy of research outputs from the DGP CRSP and Legume Innovation Lab, but was absolutely essential in ensuring that the technologies and new knowledge generated will be relevant and adopted by actors in grain legume value chains in FTF countries.

The Technical Management Advisory Committee – Innovation in Technical and Administrative Oversight and Accountability {G4}

The TMAC is a novel administrative advisory body . . . that performed both strategic planning and mentoring functions. They provided an excellent formal and informal space for USAID to receive objective assessments and constructive critiques on program technical and MO administrative performance.

The Technical Management Advisory Committee (TMAC) is a novel administrative advisory body envisioned and established by Michigan State University uniquely for the Dry Grain Pules CRSP (DGP CRSP) and the Legume Innovation Lab (LIL) to perform both strategic planning and mentoring functions.

The MO utilized the TMAC as a consultative body on emerging agricultural science and technological issues, strategies for building sustainable institutional capacity and achieving development impacts, and on program management issues.

A core function of the TMAC was to assist the MO in the monitoring and evaluation of the DGP CRSP and LIL program including: a) the monitoring of scientific quality and performance of research projects through the review of annual technical progress reports and site visits; b) the provision of technical guidance to PIs regarding annual project workplans and budgets; c) recommending institutional capacity strengthening support to partner host country institutions; and d) the identification of potential new areas and problems needing research attention.

The TMAC was comprised of two external grain legume scientists of international stature, one industry representative, one representative from a CGIAR center, three PIs elected by their peers and USAID's Agreement Officers Representative (AOR) for the program. The Director and Deputy Director of the DGP CRSP and LIL were ex-officio members without vote on the TMAC.

Michigan State University wishes to express its gratitude to the individuals who graciously served on the TMAC during the past ten years. These individuals volunteered their time and valued expertise to help make the DGP CRSP and LIL a premier international grain legume research program. Their commitment, advice and advocacy has clearly left its imprint on the scientific quality, performance and developmental outcomes of the program.

Individuals who have graciously served on the TMAC during the past ten years include:

Douglas Maxwell (chair, 2008-2013)
Julia Kornegay (chair, 2013-2017)
James Beaver
Jill Findeis
Ndiaga Cisse
Amanda Minaar (deceased)
Barry Pittendrigh
Cynthia Donovan
Clementine Dabire
Phil Miklas
Phil McClean
Mark Manary
Ousmane Coulibaly
Steve Beebe
Robin Buruchara
Ousmane Boukar
Noel Ellis
Johannes Lehmann
Constance Gewa
Bob Green
Greg Varner
Jiryis Oweis
Bahiru Duguma
Larry Beach
Jennifer "Vern" Long.

Valued lessons learned from the TMAC experience include:

1. *Recruitment and Commitment to Serve*: The MO was pleased to discover that it was relatively easy to recruit internationally recognized and highly qualified scientists and PIs to serve on the TMAC. External scientists and PIs had high regard for this USAID research program on grain legumes and considered it a worthy use of their time to serve on the TMAC. CGIAR and industry representatives welcomed the opportunity to better understand the research activities of the DGP CRSP and LIL and to identify areas for coordinating efforts.

2. *Objective external review of annual workplans, budgets and technical reports*: The MO and project PIs considered the evaluations and recommendations received from the TMAC's review of the annual project workplans, budgets and technical progress reports to be of great value. This monitoring function also brought integrity to the program and provided USAID with ongoing performance assessments. The MO acknowledges though that the workload for a volunteer body such as the TMAC was quite high and that the repetitive review of projects each year may have been unnecessary in later years of the program when research teams were mature and project approaches were set

3. *Site Visits*: Project PIs appreciated site visits both to developing country institutions, U.S. universities and the project team meetings. The TMAC made a concerted effort to send a member to each host country site, typically accompanied by project PIs, at least once during the 10 year program performance period. These site visits and feed back to the MO provided the Directors with third party insights on technical research progress toward objectives, team dynamics including collaborations between the US and HC PIs, HC PI and institutional commitment to the projects, communication between PIs and USAID country missions, and the potential of projects to contribute to developmental impacts.

4. *Contributions to Research Planning*: An extremely valuable contribution of the TMAC was their participation in the initial research planning meetings by all the project teams at the start of the LIL phase in 2013. At these meetings, the TMAC members interacted with the team members as they developed research and training workplans for their respective projects.

5. *Institutional Capacity Strengthening*: The TMAC's award recommendations to the MO following review of the institutional capacity strengthening proposals were insightful, equitable and reflected a genuine desire for the funds to benefit as many partner host country institutions as possible.

6. *USAID*: The TMAC provided an excellent formal and informal space for the USAID AOR to receive objective assessments and constructive critiques of program technical and MO administrative performance. The USAID AOR, as a full committee member, could contact and interact with TMAC members at any time regarding performance issues or questions. On one occasion, USAID invited Constance Gewa to the USAID offices in Washington to share her insights following a project site visit to Malawi.

7. *TMAC Meritorious Achievement Awards*: Perhaps the most valued TMAC initiative by the PIs was the TMAC's recognition of scientists who had made "laudable contributions to research on grain legumes and the development of technologies that benefit smallholder farmers in developing countries." These awards were presented during a special awards ceremony at DGP CRSP and LIL conferences.

TMAC Meritorious Achievement Award recipients include:

2012	Ndiaga Cisse, Juan Carlos Rosas, James Beaver, Rick Bernsten
2014	Issa Drabo, Jeff Ehlers, James Kelly
2016	Douglas Maxwell, Catherine Madata, Ibrahim Baoua, Steve Beebe
2017	Clementine Dabire, Mywish Maredia, Phil Roberts, James Steadman, Robert Mazur

TMAC Early Career Grain Legume Scientist Award recipients include:

2017	Kelvin Kamfwa, Joseph Batieno Benoit, Juan Osorno

8. *Advisement to the MO*: Access to the TMAC for consultation and advisement on administrative and budgetary decisions was greatly appreciated by the Director and Deputy Director. They were a highly trusted body who understood the DGP CRSP and LIL program better than anyone else. When difficult decisions needed to be made regarding extension/termination of projects, budgetary allocations, plans for conferences, etc., the TMAC provided wise guidance to the MO.

The TMAC has unquestionably served the DGP CRSP and LIL program well and should be considered a highly effective monitoring and advisory body for other like programs funded through the Office of Agriculture Research and Policy, Bureau of Food Security, USAID.

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APPENDIX 1.

PORTFOLIO OF PROJECTS:
Dry Grain Pulses Collaborative Research Support Program (2007-2012)

Project 1. ***Using Improved Pulse Crop Productivity to Reinvigorate Smallholder Mixed Farming Systems in Western Kenya***

LEAD U.S. PI: Julie Lauren, Cornell University

COLLABORATING PIs: John Ojiem, KARI; James Muthomi, U. Nairobi; John Okalebo, Moi University; Martins Odenbo, KARI; Samuel Mwonga, Egerton University; Beth Medvecky, Cornell University; Robin Buruchara, CIAT

LOCATION: Western Highlands of Kenya

DESCRIPTION: The project was based on the premise that pulse crops contribute to reduced pest/disease incidence, improved N fixation, and higher soil nutrient accumulation in smallholder farm systems, which ultimately reduce risk, benefit system productivity, food security and human nutrition. Project activities included farmer participatory evaluation of vigor enhancing strategies by 70 collaborating farmers across a soil fertility gradient; farmer training on yield enhancing technologies; exchange visits to promote farmer learning and knowledge sharing; and implementation of researcher managed replicated experiments. Farmers achieved the largest bean yield gains when planting and improved bean variety and applying triple super phosphate to soil.

Project 2. ***Enhancing Nutritional Value and Marketability of Beans through Research and Strengthening Key Value Chain Stakeholders in Uganda and Rwanda***

LEAD U.S. PI: Robert Mazur, Iowa State University

COLLABORATING PIs: Dorothy Nakimbugwe, Makerere University; Michael Ugen, NaCRRI; Henry Kizito Musoke, Volunteer Efforts for Development Concerns, Uganda; Hilda Vasanthakaalam, Kigali Institute of Science and Technology, Rwanda

LOCATION: Uganda and Rwanda

DESCRIPTION: The objectives of the project were (1) to improve bean yields and quality through evaluation and promotion of better production practices, (2) to support sustainable community-based seed production systems, (3) to reduce postharvest losses through solarization and hermetic storage of bean grain, (4) to evaluate development interventions that promote adoption of improved integrated crop management practices and technologies, and (5) to strengthen learning and sharing of innovative practices among value chain stakeholders. Outputs of the project included community-based production of quality bean seed, the development of printed and video extension materials on improved crop management practices, the development of appealing, nutrient-enhanced and shelf-stable value-added bean products, and strengthened collective marketing of bean grain by smallholder farmer groups.

Project 3. ***Combining Conventional, Molecular and Farmer Participatory Breeding Approaches to Improve Andean Beans for Resistance to Biotic and Abiotic Stresses in Ecuador and Rwanda***

LEAD U.S. PI: James Kelly, Michigan State University

COLLABORATING PIs: George Abawi, Cornell University; Sieglinde Snapp, Michigan State University; Eduardo Peralta, INIAP, Ecuador; Louis Butare, RAB, Rwanda

LOCATION: Ecuador and Rwanda

DESCRIPTION: The objective of the project was to utilize traditional breeding and marker-assisted selection approaches to genetically improve large seeded Andean beans for production in the highlands of Ecuador, Rwanda and the Midwestern U.S. Achievements by the project include the release of 27 new varieties, sustained and expanded bean breeding programs at INIAP-Ecuador and RAB-Rwanda through farmer participatory breeding activities with an emphasis on gender and germplasm exchange between programs. Specific research outputs included the characterization of a new rust strain (race 22:2), the identification of new races of rust from Ecuador, and the identification and characterization of new races of anthracnose also from Ecuador, and the validation of an improved staking technology for climbing beans in Rwanda that utilizes less staking wood and more strings and cords.

Project 4. ***Expanding Pulse Supply and Demand in Africa and Latin America: Identifying Constraints and New Strategies***

LEAD U.S. PI: Richard Bernsten, Michigan State University

COLLABORATING PIs: David Kiala, UJES, Angola; Feliciano Mazuze, IIAM, Mozambique; Juan Carlos Rosas, EAP, Honduras; Cynthia Donovan, Duncan Boughton and Eric Crawford, Michigan State University

LOCATION: Angola, Mozambique and Honduras

DESCRIPTION: The research in Angola used a value-chain approach to evaluate key factors affecting the competitiveness of domestic dry beans and cowpeas. In Mozambique, IIAM researchers identified the lack of information and analyses as key constraints to improving the performance and sustainability of bean and cowpea value chains. In Honduras, the research focused on developing sustainable bean production practices and increasing farmers' income through the sale of fair trade beans to U.S. markets. The project identified organic fertilizers, pest and disease control practices that would improve the sustainability of smallholder bean production systems.

Project 5. ***Improving Bean Production in Drought-Prone, Low Fertility Soils of Africa and Latin America- An Integrated Approach***

LEAD U.S. PI: Jonathan Lynch, Pennsylvania State University

COLLABORATING PIs: Celistina Jochua and Magalhaes Miguel, IIAM, Mozambique; Juan Carlos Rosas, EAP, Honduras, Soares Almeida Xerinda, IIAM, Mozambique; Kathleen Brown and Jill Findeis, Pennsylvania State University

LOCATION: Mozambique and Honduras

DESCRIPTION: The objective of this project was to improve bean productivity by developing new bean cultivars with root traits that improved growth and grain yield in stressful soil environments. Root traits that were found to be important for bean growth in stress environments included basal root whorl number, root hair length and density. The use of genetic multi-lines was also demonstrated as a desirable planting strategy for farmers facing uncertain environmental stress conditions. Introgression of root traits into elite lines has generated improved bean varieties with substantially greater stress tolerance in Mozambique.

Project 6. ***Modern Cowpea Breeding to Overcome Critical Production Constraints in Africa and the U.S.***

LEAD U.S. PI: Phil Roberts, University of California, Riverside

COLLABORATING PIs: Ndiaga Cisse, ISRA, Senegal; Antonio Chicapa Dovala, IIA, Angola; and Issa Drabo, INERA, Burkina Faso

LOCATION: Angola, Burkina Faso and Senegal

DESCRIPTION: The primary objectives were: 1) to develop improved, pest resistant and drought tolerant cowpea varieties for sub-Saharan Africa and the U.S. using modern breeding tools; to strengthen cowpea seed production and delivery systems to ensure access to improved varieties; and 3) to develop a cowpea breeding program in Angola and strengthen programs in Burkina Faso and Senegal. In Burkina Faso, six new cowpea varieties were released including 'Melakh' developed in Senegal under the Bean/Cowpea CRSP. In Senegal, ISRA-2065 ('Pakau') containing thrips and aphid resistance was released in 2011.

Project 7. ***Biological Foundations for Management of Field Insect Pests of Cowpea in Africa***

LEAD U.S. PI: Barry Pittendrigh, University of Illinois at Urbana-Champaign

COLLABORATING PIs: Ibrahim Baoua, INRAN, Niger; Clementine Dabire and Malick Ba, INERA, Burkina Faso; Manuele Tamo, IITA, Benin; Momadou N'Diaye, IRE, Mali; Mohammed Ishiyaku, IAR, Nigeria; Julia Bello Bravo, UIUC

LOCATION: Burkina Faso, Niger, Nigeria, Benin, Mali

DESCRIPTION: This project sought to lay the foundation for the deployment of cost-effective and environmentally benign insect control practices that involve local materials, biological control agents and approaches that empower women through cottage industries involving cutting-edge genomic tools. The strategy which utilizes genomic tools combined with an in-depth understanding of pest populations in the field to guide the development of solutions and decisions for pest control is called "IPM-omics." A key research outcome was a formulation of neem extract combined with an insect-specific virus that doubled cowpea yield when applied at appropriate times on smallholder farms in Benin. Animation videos on cowpea IPM topics were also developed by the project which could readily be voice-overlaid in local languages.

Project 8. ***Development, Testing and Dissemination of Genetically Improved Bean Cultivars for Central America, the Caribbean and Angola***

LEAD U.S. PI: James Beaver, University of Puerto Rico

COLLABORATING PIs: Juan Carlos Rosas, EAP, Honduras; Emmanuel Prophete, National Seed Program, Haiti; Antonio Chicapa Dovala, IIA, Angola; Consuelo Estevez de Jensen, UPR, and Timothy Porch, USDA-ARS Tropical Agriculture Research Station, Puerto Rico

LOCATION: Honduras, Haiti and Angola

DESCRIPTION: The primary objectives of this project were to develop, release and disseminate improved bean cultivars with BGYMV, BCMV, and CBB resistance, heat tolerance and adaptation to low fertility soils for the lowland tropics, to develop molecular markers for disease resistance genes, and to evaluate the potential to produce lima bean and pigeon pea within Central America and the Caribbean. Seventeen disease resistant small red, black, white and red-mottled bean cultivars were developed and released in Central American countries and in Haiti. A dominant gene (Xap-1) conferring resistance to common bacterial blight was identified. Bean lines were identified that developed nodules and yielded well when inoculated with *Rhizobium* strains CIAT899 and UMR1597. The project also sought to increase the capacity, effectiveness, networking and sustainability of NARS research programs that serve the bean and cowpea sectors in Central America, Haiti and Angola.

Project 9. ***Enhancing Biological Nitrogen Fixation of Leguminous Crops Grown on Degraded Soils in Uganda, Rwanda and Tanzania***

LEAD U.S. PI: Mark E. Westgate, Iowa State University

COLLABORATING PIs: John Steve Tenywa, Makerere University, Uganda; Lynne Carpenter-Boggs, Washington State University; Karen Cichy, USDA-ARS, Michigan State University; James Kelly, Michigan State University; Phillip Miklas, USDA-ARS, Washington; Henry Kizito Musoke, VEDCO, Uganda

LOCATION: Uganda, Rwanda, Tanzania

DESCRIPTION: The strategic aims to this project were: (1) to significantly improve the biological nitrogen fixation (BNF) and seed yields for of common bean using superior rhizobium inoculants and improved varieties; (2) to examine the inheritance of genetic and environmental variation of BNF in common bean of Andean origin; and (30 to improve the productivity, profitability, and sustainability of agricultural systems on degraded soils through effective dissemination of BNF technologies to smallholder farmers. Soil analyses revealed extreme deficiencies in macro- and micronutrients that limited the activity and effectiveness of rhizobium inoculants in Central and Eastern Africa.

Project 10. ***Increasing Utilization of Cowpeas to Promote Health and Food Security in Africa***

LEAD U.S. PI: Joseph Awika, Texas A&M University

COLLABORATING PIs: John Shidano, Kalaluka Lwanga Munyinda, University of Zambia; Kennedy Muimui, ZARI, Zambia; Abdul Faraj, Prisca Tuitoek, Egerton University, Kenya; Amanda Minnaar (deceased), Gyebi Doudu, University of Pretoria, South Africa; Susanne Talcott and Bir Bahadur Singh, TAMU

LOCATION: Kenya, Zambia

DESCRIPTION: The project aimed to discover bioactive compounds in cowpea, their potential to reduce inflammation and oxidative stress relevant to gut health, infant immunity and various chronic diseases, and how cowpea seed coat color relates to bioactive compound composition. Light brown cowpea lines had the highest content of tannin which correlated with strong oxidative stress inhibition. Red cowpea lines had the most flavonoids which correlated with prevention of chronic inflammation. Cooking and simulated gastric digestion did not reduce the measured bioactivity in the cowpeas.

Project 11. ***Pulse Value Chain Initiative- Zambia (PVCI-Z)***

LEAD U.S. PI: Vincent Amanor-Boadu, Kansas State University

COLLABORATING PIs: Gelson Tembo, Mukwiti Mwiinga, University of Zambia; Allen Featherstone and Kara Ross, Kansas State University

LOCATION: Zambia

DESCRIPTION: This project provided baseline information about the bean and cowpea value chains in Zambia to facilitate enhanced total chain performance, increased producer incomes, and increase food security among pulse growers in Zambia. The goal was to develop a better appreciation for pulses in the food security profile of Zambian producers, since pulses have been viewed as a minority crop in Zambia.

Project 12. ***Impact Assessment of Bean/Cowpea and Dry Grain Pulses CRSP Investments in Research, Institutional Capacity Building, and Technology Dissemination in Africa, Latin America and the U.S.***

LEAD U.S. PI: Mywish Maredia, Michigan State University

COLLABORATING PIs: Richard Bernsten, Eric Crawford and Byron Reyes, Michigan State University

LOCATION: Haiti, Ecuador, Honduras, Senegal, Burkina Faso,

DESCRIPTION: The project compiled two important data bases: 1. a database of improved varieties of beans and cowpeas released in host countries which participated in the Bean/Cowpea CRSP, and 2. a database of socioeconomic studies and impact assessments with support from the Bean/Cowpea and Dry Grain Pulses CRSPs. In addition, ex post impact assessment studies were conducted on the adoption of improved bean and cowpea varieties in Central America and Ecuador plus in Senegal. *Amadeus 77*, a small red bean variety released by EAP Zamorano-Honduras accounted for approximately 50% of the harvested area of beans in Central America, providing a regional internal rate of return (IRR) of 32%. Improved CRSP cowpea varieties account for 44% of the production area in three growing regions of Senegal, producing an IIR of 18% and a net present value of $78.6 million.

APPENDIX 2.

PORTFOLIO OF PROJECTS:
Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (2013-2017)

Project 1. (SO1.A1) *Genetic Improvement of Middle-American Climbing Beans for Guatemala*

LEAD U.S. PI: Juan M. Osorno, North Dakota State University

COLLABORATING PIs: Julio C. Villatoro, Angela Miranda, Jessica Moscoso, Gustavo Mejia, and Edgardo Carrillo, ICTA, Guatemala; Phil McClean, North Dakota State University

LOCATION: Western highlands of Guatemala

DESCRIPTION: Research objectives were to: (a) breed higher yielding Middle-American climbing bean lines with improved disease resistance and agronomic performance, and to (b) characterize the genetic diversity of this germplasm using genomic tools. Two germplasm collections of climbing beans from Guatemala were genetically characterized using 42k SNP markers. Results confirmed the presence of a new distinct race of common bean within the Middle American gene pool known as race 'Guatemala.' Results enable the identification of important genomic regions associated with traits of agronomic/economic importance for future bean breeding. Two new climbing bean varieties were released, 'ICTA-Labor Ovalle' and 'ICTA-Utatlan', adapted to the agro-ecologies and the Milpa intercropping system of the Guatemalan highlands. A long-term breeding plan for climbing beans was developed for ICTA-Guatemala providing a roadmap for future research on genetic improvement of climbing beans regardless of the future availability of external funding.

Project 2. (SO1.A2) *Improving Photosynthesis in Grain Legumes with New Plant Phenotyping Technologies*

LEAD U.S. PI: David M. Kramer, Michigan State University

COLLABORATING PIs: Phil Roberts and Timothy J. Close, University of California, Riverside; Maren Friesen, James Kelly, and Wayne Loescher, Michigan State University; Kennedy Muimui, ZARI, Zambia; Kelvin Kamfwa, University of Zambia

Location: Zambia

DESCRIPTION: The project sought to increase the productivity of grain legume crops in Africa by improving the robustness and efficiency of photosynthesis using new phenotyping technologies (PhotosynQ and MultispeQ) and advanced genetics and genomics approaches. QTLs for drought tolerance were identified in common bean in Zambia utilizing MultispeQ to measure photosynthetic parameters under varying water deficit regimes. Leaf cooling through transpiration was demonstrated as being important for heat tolerance and the function of photosynthetic processes in common bean under high temperatures. Breeding for heat tolerance in bean should include phenotyping and selection of lines with associated traits (e.g., stomatal conductance, etc.). Lipid membrane and ATP synthase were mapped in cowpea to identify QTLs for photosynthetic efficiency and enabling investigation into the biochemical mechanisms for cold tolerance.

Project 2. (SO1.A3) *Improving Genetic Yield Potential of Andean Beans with Increased Resistances to Drought and Major Foliar Diseases and Enhanced Biological Nitrogen Fixation (BNF)*

LEAD U.S. PI: James D. Kelly, Michigan State University

COLLABORATING PIs: Stanley Nkalubo, NaCRRI, Uganda; Kennedy Muimui, ZARI, Zambia; Wayne Loescher, MSU; James Steadman, UNL; Carlos Urrea, Univ. Nebraska, Scottsbluff; Karen Cichy, USDA–ARS, MSU

LOCATION: Uganda and Zambia

DESCRIPTION: Bean production is constrained in Uganda and Zambia by abiotic and biotic stresses. This project sought to develop improved varieties of Andean bean market classes that: a) Combine resistances to foliar diseases, drought, and improved BNF; b) 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; c) Identify QTLs for drought tolerance, disease resistance, cooking time, and BNF for use in MAS to improve germplasm; and d) Develop phenometric methods to improve the efficiencies of breeding for abiotic stress tolerance. Resistance genes for rust, CBB, BCMV, *Sclerotium* root rot and drought were identified and introgressed into Uganda bean lines of Andean market classes. Seven bean lines with shorter cooking time and preferred by farmers were selected through PVS in Uganda.

Project 4. (SO1.A4) *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*

LEAD U.S. PIs: James Beaver, University of Puerto Rico, Mayaguez, Puerto Rico

COLLABORATING PIs: Juan Carlos Rosas, EAP–Zamorano, Honduras; Julio Cesar Villatoro, ICTA, Guatemala; Emmanuel Prophete, NSS, Haiti; Consuelo Estevez de Jensen, UPR; Timothy Porch, USDA/ARS/TARS, Puerto Rico; Phil Miklas, USDA/ARS, Prosser, WA; Juan Osorno and Phil McClean, NDSU

LOCATION: Honduras, Haiti and Guatemala

DESCRIPTION: This project sought to incorporate resistance genes to biotic and abiotic constraints that limit bean productivity in the tropical lowlands of Central America and the Caribbean. Novel QTLs for resistance to angular leaf spot and halo bacterial blight were identified in mesoAmerican bean lines. The first tepary (*Phaseolus accutifolius*) bean breeding lines with tolerance to BGYMV were developed and novel sources of resistance to BCMNV and web blight identified for future introgression. A genetic marker for resistance to common bean weevil, *Acanthoscelides obtectus*, a major grain storage pest in Africa and Latin America, was identified and is being used to accelerate the breeding of weevil resistant bean varieties. A newly developed BGYMV resistant determinant black bean variety adapted to the tropical lowlands, 'Patriarca', was released by ICTA in Guatemala. A new black bean variety with multiple virus resistances and drought tolerance, 'Lenca Precóz', was released in Honduras. Superior meso-American bean lines were identified that combine good yield potential with excellent nodulation in low N soils.

Project 5. (SO1.A5) *Genetic Improvement of Cowpea to Overcome Biotic Stress and Drought Constraints to Grain Productivity*

LEAD U.S. PI: Philip A. Roberts, University of California, Riverside

COLLABORATING PIs: Benoit Joseph Batieno, INERA, Burkina Faso; Ibrahim Atokple and Francis Kusi, SARI, Ghana; Ndiaga Cisse, ISRA, Senegal; Timothy J. Close and Bao-Lam Huynh, UCR.

LOCATION: Burkina Faso, Ghana and Senegal

DESCRIPTION: The project applied genomics and modern breeding to improve cowpea yield by targeting insect resistance. The focus of the research was to: a) discover insect tolerance and resistance QTLs for cowpea breeding; b) increase African and U.S. cowpea productivity by improving varieties with resistance to insect stresses, drought tolerance, and disease resistance. 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 in WA. Genetic mapping of the aphid resistance in IT97K-556-6 at UCR revealed two QTLs on cowpea linkage groups LG1 and LG7. Four pre-release LIL advanced cowpea lines were evaluated for yield and insect resistance by INERA in multi-locational trails and the release petition scheduled for 2019 in Burkina Faso. Formal release of five large white-seeded CRSP cowpea varieties in Senegal by ISRA was followed up with additional Breeder and Foundation Seed production of each variety.

Project 6. (SO1.B1) ***IPM-omics: Scalable and Sustainable Biological Solutions for Pest Management of Insect Pests of Cowpea in Africa***

LEAD U.S. PIs: Barry Pittendrigh, University of Illinois at Urbana–Champaign

COLLABORATING PIs: Manuele Tamò, IITA–Benin; Clémentine Dabiré-Binso and Fousséni Traore, INERA–Burkina Faso; Laouali Amadou, INRAN; Ibrahim Baoua, University of Maradi-Niger; Stephen Asante, SARI; Moses Mochaih, Haruna Braimah, CRI-Ghana; Julia Bello-Bravo, UIUC; and Eustache Biaou, INRAB–Benin.

LOCATION: Burkina Faso, Ghana and Niger

DESCRIPTION: This project sought to develop sustainable insect pest management techniques to improve cowpea crop yields. The research objectives were to: a) Define the insect pest problems on cowpea; b) Develop IPM solutions: environmentally and economically appropriate pest control solutions for smallholder cowpea production systems; and c) Scaling up solutions. Bio-control agents have been developed and are available for scale-up for management of cowpea insect pests in West African cropping systems. Studies were completed on insect behavior, ecology and biology to maximize the impact of biocontrol agents in the field. Sex pheromones were identified for *Clavigralla tomentosicollis*, a pod sucking bug, and are being chemically characterized for attracting egg foraging parasitoids. The neem and viral spray strategy to control *Maruca vitrato* pod borer was field-tested on large scale with cowpea farmers in Benin. Parasitoid species (*Therophilus javanus* and *Phanerotoma syeptae*) released in 2016 were found to have survived the dry period on host plant species in Benin. Survey findings have informed the new parasitoid release strategy for *M. vitrata* control.

Project 7. (SO2.1) ***Farmer Decision Making Strategies for Improved Soil Fertility Management in Maize–Bean Production Systems***

LEAD U.S. PI: Robert Mazur, Iowa State University

COLLABORATING PIs: Moses Tenywa and Richard Miiro, Makerere University, Uganda; Onesimus Semalulu, NARL, Uganda; Ricardo Maria and Sostino Mocumbe, IIAM-Mozambique; Eric Abbot, Andrew Lenssen, and Ebby Luvaga, ISU; Russell Yost, University of Hawaii, Manoa; and Julia Bello-Bravo, UICC

LOCATION: Uganda and Mozambique

DESCRIPTION: This project developed methods and procedures to enable smallholder farmers with varying education levels to better diagnose soil-related production constraints and to make improved site-specific cropping system management decisions that contribute to higher productivity of beans and associated crops and, over time, improved soil fertility. It also assessed the effectiveness of innovative communication approaches and technologies to engage farmers with diverse characteristics and other key stakeholders in widespread dissemination and adoption of diagnostic and decision support aids. A soil mapping approach was developed and validated to assist farmers in making soil fertility management decisions in accord with variations in soils within farm landscapes. A multi-stakeholder bean Innovation Platform continues to grow in membership, diversity, enthusiasm and capability with 10 value-chain member organizations and 1000+ farmers. Two SAWBO video animations were released on research-based farmer-validated bean production recommendations in Uganda and Mozambique and one on jerry can storage for Mozambique.

Project 8. (SO2.2) ***Enhancing Pulse Value-Chain Performance through Improved Understanding of Consumer Behavior and Decision-Making***

LEAD U.S. PI: Vincent Amanor-Boadu, Kansas State University

COLLABORATING PIs: Gelson Tembo, University of Zambia; Lawrence Mapemba, LUANAR, Malawi; Fredy Kilima, Sokoine University of Agriculture, Tanzania; Allen Featherstone and Kara Ross, KSU.

LOCATION: Zambia, Malawi and Tanzania

DESCRIPTION: Increasing bean consumption to support smallholder producers' economic well-being requires an appreciation of consumer characteristics, decisions, and choices. The project worked to develop an understanding of factors shaping consumers' food choice decisions to facilitate improvements in legume value chains. Surveys revealed that bean grain size, color, gravy quality and cooking time are important determinants of consumer preference. "Beans for Health and Wealth" national conferences were held in Lilongwe, Malawi (March 14-15, 2017) and in Lusaka, Zambia (June 7-8, 2017). The objectives of the conferences were to share research findings regarding bean markets and their consumers. Nearly 600 persons (researchers, grain traders, processors, aspiring farmers, agriculture service providers and government personnel) participated in the conferences. Breeding strategies, nutrition policies and programs to promote bean consumption were considered.

Project 9. (SO3.1) ***Legumes, Environmental Enteropathy, the Microbiome and Child Growth in Malawi***

LEAD U.S. PI: Mark Manary, Washington University School of Medicine in St Louis, Missouri

COLLABORATING PIs: Ken Maleta and Chrissie Thakwalakwa, University of Malawi College of Medicine, Malawi; Indi Trehan, Washington University School of Medicine in St. Louis

LOCATION: Malawi

DESCRIPTION: Environmental enteropathic dysfunction (EED), a pervasive, chronic subclinical inflammatory condition among children places them at high risk for stunting, malabsorption, and poor oral vaccine efficacy. Minimizing EED is an essential step in improving the survival and growth of at-risk children. This project conducted two randomized, controlled clinical trials to determine if common beans or cowpeas improve growth, ameliorate EED, and alter the intestinal microbiome during this high-risk period. The first study involved 6–11-month-old children who received beans, cowpeas, or standard local complementary foods for six months; the second randomized, controlled trial enrolled 12–35-month-old children and followed them for 12 months. The addition of cowpea (4.6-5.2 g protein/day and 4-5 g/day of indigestible carbohydrate) to complementary feeding in Malawian infants (6 to 12 mo of age) resulted in less linear growth faltering (reduced stunting). The addition of bean to complementary feeding of rural Malawian children (12-36 months) led to an improvement in a biomarker of gut health, but did not directly translate in improved linear growth of infants. Food metabolite analyses identified potential dietary biomarkers of legume intake for stool and urine samples that could be used to assess the relationship between distinct legume consumed and health outcomes. Dietary biomarkers of legume intake include pipecolic acid and oleanic acid for common bean and quercetin and α and γ-tocopherol acid for cowpea intake.

Project 10. (SO4.1) ***Impact Assessment of Dry Grain Pulses CRSP Investments in Research, Institutional Capacity Building and Technology Dissemination for Improved Program Effectiveness***

LEAD U.S. PI: Mywish Maredia, Michigan State University

COLLABORATING PIs: Eric Crawford, Robert Shupp, Nicole Mason, Nathalie MeNsope, David DeYoung, MSU; Byron Reyes, CIAT; Fulgence Mishili and Paul Kusolwa, SUA; Francis Kusi, SARI; Dieudonne Ilboudo, INERA

LOCATION: Guatemala, Zambia, Tanzania, Burkina Faso, Haiti

DESCRIPTION: This project aimed to: a) Provide technical leadership in the design, collection, and analysis of data for strategic input and impact evaluation; b) Conduct ex ante and ex post impact assessments on the economics of supply and demand for the sustainable development of grain legume seed systems. Case studies in Zambia and Uganda indicated that incorporating legume crops in cropping system either as rotation crop or inter-crop positively effects indicators of household income, production, food security and dietary diversity. Quality seeds were shown to perform better in terms of germination rate, plant population and yield relative to recycled grain of legume crops. Thus, to increase productivity, it is not sufficient to promote only the adoption of improved varieties, but also the planting of quality seed. Studies also showed that farmers are able to perceive quality differences in planting material and are willing to pay a premium for "quality" bean seed. Although 30-35% of farmers' WTP for quality seed was above the price of certified seed, farmers' use of purchased certified seeds or QDS is in practice much lower than reflected in the percentage of farmers WTP a premium for quality seed.

Project 11. ***Haiti Bean Seed Security Project- Mwen Gen Pwa***

LEAD U.S. PIs: Irvin Widders and Luis Flores, Michigan State University

COLLABORATORS/SUBCONTRACTED PARTNERS: Inter-American Institute for Cooperation in Agriculture (IICA-Haiti); National Seed System, Ministry of Agriculture, Haiti

LOCATION: Haiti

DESCRIPTION: The Mwen Gen Pwa (MGP) project, a buy-in from the USAID Mission to Haiti, was an emergency relief response to Hurricane Matthew in the southwestern region of Haiti. The project aimed to distribute quality seed of proven improved and locally adapted varieties of black bean and pigeon pea to farmers in the Sud and Grand-Anse Departments that were adversely affected by the hurricane. The objectives of the project were to:

- Reach at least 6,000 households with quality-declared seed of improved small black bean varieties with high yield potential and adapted to the agro-climatic conditions of the target regions in Haiti (requiring low use of inputs).
- Distribute bean seed during two planting seasons in two target areas (3,000 households in Sud and 2,000 in Grand-Anse, plus 2,000 more in June across both regions).
- Provide basic technical assistance to households on the appropriate cultural management of the improved bean varieties by resource-poor smallholder farmers.

APPENDIX 3.

Bibliography of Publications by the Dry Grain Pulses CRSP: FY2006 to FY2012

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I. GENETIC IMPROVEMENT

A. Refereed Journal Articles

Agbicodo, E.M., C.A. Fatokun, R. Bandyopadhyay, K. Wydra, N.N. Diop, W. Muchero, J.D. Ehlers, P.A. Roberts, T.J. Close, R.G.F. Visser, and C.G. van der Linden. 2010. Identification of markers associated with bacterial blight resistance loci in cowpea [Vigna unguiculata (L.) Walp.]. Euphytica. DOI: 10.1007/s10681-010-0164-5.

Awale, H. E. Falconi, J. C. Villatoro and J.D. Kelly. 2008. Control y caracterizacion de aislamientos de Colletotrichum lindemuthianum de Ecuador y Guatemala. Revista Agronomía Mesoamericana 19: 1-6.

Barrera-Figueroa, B., Gao, L., Diop, N.-N., Wu Z., Ehlers, J., Roberts, P.A., Close, T.J., Zhu, J.-K. and Liu, R. 2011. Identification and comparative analysis of drought-associated microRNAs in two cowpea genotypes. BMC Plant Biology 2011, 11:127. doi:10.1186/1471-2229-11-127.

Beaver JS, Porch TG, Zapata M. 2010. Registration of 'Badillo' Light Red Kidney Bean. Journal Plant Registrations 4:1-4.

Beaver, J.S., M. Zapata, M. Alameda, T.G. Porch and J.C. Rosas. 2011. Registration of PR0401-259 and PR0650-31 dry bean germplasm lines. J. Plant Reg. Reg. doi: 10.3198/jpr2011.05.0283crg; Published online 9 Nov. 2010.

Cichy, K.A., M. W. Blair, C. H. Galeno-Mendoza, S. S. Snapp, and J.D. Kelly. 2009. QTL analysis of root architecture traits and low phosphorus tolerance in an Andean bean population. Crop Sci. 49:59-68.

Das, S., D.A. DeMason, J.D. Ehlers, T.J. Close, and P.A. Roberts. 2010. Transcriptional profiling of root- knot nematode induced feeding sites in cowpea (Vigna unguiculata L. Walp.) using a soybean genome array. BMC Genomics 2010, 11:480. doi:10.1186/1471 2164-11-480.

Diouf, D., N. Cisse and M. Timko. 2012. Genetic relationship of cowpea [Vigna unguiculata (L.) Walp.] varieties from Senegal based on SSR markers. Genetics and Molecular Research 11(1): 292-304. DOI http://dx.doi.org/10.4238/2012.February.8.4

Dorcinvil R, Sotomayor-Ramírez D, Beaver JS. 2010. Agronomic performance of common bean (Phaseolus vulgaris L.) lines in an Oxisol. Field Crops Research. 118:264-272.

Ehlers, J. D., B.L. Sanden, C.A. Frate, A.E. Hall, and P.A. Roberts. 2009. Registration of 'California Blackeye 50' Cowpea. Journal of Crop Registrations 3:236-240.

Ernest, E.G., E. Falconí, E. Peralta and J. D. Kelly. 2008. Uso de una encuesta a agricultores para orientar el fitomejoramiento de frijol en Ecuador. Revista Agronomía Mesoamericana 19: 7-18.

Guachambala MS and Rosas JC. 2010. Caracterización molecular de accesiones cultivadas y silvestres de frijol común de Honduras. Agronomía Mesoamericana 21(1):1-10.

Henry A, Rosas, JC, Beaver JS, Lynch JP. 2010. Multiple stress response and belowground competition in multilines of common bean (Phaseolus vulgaris L.). Field Crops Research 117:209-218.

Kwapata, K., R. Sabzikar, M. B. Sticklen, and J. D. Kelly. 2010. In vitro regeneration and morphogenesis studies in common bean. Plant Cell Tiss Organ Cult: J. Plant Biotechnology. 100:97–105.

Lucas, M.R., N.-N. Diop, S. Wanamaker, J.D. Ehlers, P.A. Roberts, and T.J. Close. 2011. Cowpea-soybean synteny clarified through an improved genetic map. The Plant Genome 4:1-11. doi:10.3835/plantgenome2011.06.0019.

Mbogo KP, Davis J, Myers JR. 2009. Transfer of the Arcelin-Phytohaemagglutinin-α Amylase Inhibitor Seed Protein Locus from Tepary bean (Phaseolus acutifolius A. Gray) to common bean (P. vulgaris L.). Biotechnology 8:285-295.

Miklas, P.N., S. P. Singh, H. Terán, J. D. Kelly, and J. R. Smith. 2011. Registration of common bacterial blight resistant cranberry dry bean germplasm line USCR-CBB-20. J. Plant Reg. 5:98-102.

Mkwaila, W., K.A. Terpstra, M. Ender, and J.D. Kelly. 2011. Identification of QTL for resistance to white mold in wild and landrace germplasm of common bean. Plant Breeding 130:665-672.

Muchero, W., J.D. Ehlers, and P.A. Roberts. 2008. Seedling Stage Drought-Induced Phenotypes and Drought-Responsive Genes in Diverse Cowpea Genotypes. Crop Science 48:541-552.

Muchero, W., J.D. Ehlers, and P.A. Roberts. 2009b. Restriction fragment length polymorphism-based candidate gene mapping for seedling drought tolerance in cowpea (Vigna unguiculata L. Walp.). Theoretical and Applied Genetics 120:509-518.

Muchero, W., J.D. Ehlers, and P.A. Roberts. 2009c. QTL analysis for resistance to foliar damage caused by Thrips tabaci and Frankliniella schultzei (Thysanoptera: Thripidae) feeding in cowpea (Vigna unguiculata L. Walp.). Molecular Breeding 25:47-56.

Muchero, W., J.D. Ehlers, T.J. Close and P.A. Roberts. 2011. Genic SNP markers and legume synteny reveal candidate genes underlying QTL for Macrophomina phaseolina resistance and maturity in cowpea [Vigna unguiculata (L) Walp.]. BMC Genomics 12:8.

Muchero, W., J.D. Ehlers, T.J. Close, and P.A. Roberts. 2009a. Mapping QTL for drought stress-induced premature senescence and maturity in cowpea (Vigna unguiculata (L.) Walp). Theoretical and Applied Genetics 118:849-863.

Muchero, W., N.N. Diop, P.R. Bhat, R.D. Fenton, S. Wanamaker, M. Pottorff, S. Hearne, N. Cisse, C. Fatokun, J.D. Ehlers, P.A. Roberts, and T.J. Close. 2009d. A consensus genetic map of cowpea [Vigna unguiculata (L) Walp.] and synteny based on EST-derived SNPs. Proceedings of the National Academy of Sciences, USA 106:18159-18164.

Muchero, W., P.A. Roberts, Ndeye-Ndack Diop, I. Drabo, N. Cisse, T.J. Close, S. Muranaka, O. Boukar and J.D. Ehlers. 2011. Genetic architecture of delayed senescence, grain and biomass yield under drought stress in cowpea. PLoS ONE (in press).

Musoni, A., P. Kimani, R. D. Narla, R. Buruchara and J. Kelly. 2010. Inheritance of Fusarium wilts (Fusarium oxysporum f. sp. phaseoli) resistance in climbing beans. African J. Agric. Res. 5(5):399-404.

Muurinen S, Slafer GA, Peltonen-Sainio P. 2006. Breeding effects on nitrogen use efficiency of spring cereals under northern conditions. Crop Sci. 46, 561–568.

Ohkura, M., Abawi, G. S., Smart, C. D., and Hodge, K. T. 2009. Diversity and aggressiveness of Rhizoctonia solani and Rhizoctonia-like fungi on vegetables in New York. Plant Dis. 93:615-624.

Porch TG, Smith JR, Beaver JS, Griffiths PD, Canaday CH. 2010. TARS-HT1 and TARS-HT2 Heat-tolerant Dry Bean Germplasm. HortScience 45:1278-1280.

Porch, T.G., C.C. Urrea, J. S. Beaver, S. Valentin, P. A. Peña, and J. R. Smith. 2011. Registration of TARS- MST1 and SB-DT1 multiple-stress-tolerant black bean germplasm. J. Plant Reg. doi: 10.3198/jpr2010.08.0501crg; Published online 8 August 2011.

Rodriguez O., J.C. Rosas. 2010. Selección de genotipos de frijol común por su resistencia al tizón bacteriano. Agronomía Mesoamericana 21(2):1-6.

Salem, N.M., J.D. Ehlers, P.A. Roberts and J.C.K. Ng. 2010. Biological and molecular diagnosis of seed- borne viruses in cowpea germplasm of geographically diverse subSaharan origins. Plant Pathology 59:773-784.

Sawadogo, A., B. Thio, S. Kiemde, I. Drabo, C. Dabire, J. Ouedraogo, T. R. Mullens, J.D. Ehlers, and P.A. Roberts. 2009. Distribution and prevalence of parasitic nematodes of cowpea (Vigna unguiculata) in Burkina Faso. Journal of Nematology 41:120-127.

Tako, E., R.P. Glahn, J. M. Laparra, R.M. Welch, X. Lei, J.D. Kelly, M.A. Rutzke and D.D. Miller. 2009. Iron and zinc bioavailabilities to pigs from red and white beans (Phaseolus vulgaris L.) are similar. J. Agric. Food Chem. 57: 3134–3140.

Tonessia C., M. Wade, N. Cissé and S. Aké. 2009. Caractérisation de Striga gesnerioides (Willd.) Vatke du Sénégal: réactions de plusieurs cultivars de niébé (Vigna unguiculata (L.) Walp.). Journal of Applied Biosciences 24:1462-1476.

Vallejo, V., and J. D. Kelly. 2009. New insights into the anthracnose resistance of common bean landrace G 2333. The Open Horticulture J. 2:29-33.

Wright, E.M., and J.D. Kelly. 2011. Mapping QTL for seed yield and canning quality following processing of black bean (Phaseolus vulgaris L.). Euphytica 179:471–484.

Xu, P., X. Wu, B. Wang, Y. Liu, J.D. Ehlers, T.J. Close, P.A. Roberts, N.N. Diop, D. Quin,T. Hu, Z. Lu, and G. Li. 2011. A SNP and SSR based genetic map of Asparagus Bean (Vigna. unguiculata ssp sesquipedialis) and comparison with the broader species. PLoS One 6: e15952.

Zapata, M., J.S. Beaver and T.G. Porch. 2011. Dominant gene for common bean resistance to common bacterial blight caused by Xanthomonas axonopodis pv. Phaseoli. Euphytica 179:373-382.

B. Other Publications

(reports, conference papers, working papers, manuals, etc.)

Abawi, G. S., T. G. Porch, and J. D. Kelly. 2011. Field and greenhouse evaluation of bean germplasm for root rot and other diseases in New York, 2010. Bean Improvement Cooperative (BIC) 54: 142- 143.

Brisco, E.I., T. G. Porch, and J.D. Kelly. 2011. Comparison of choice versus no-choice tests of a dry bean IBL population for resistance to potato leafhopper. Annu. Rep. Bean Improv. Coop. 54:88-89.

Kelly, J.D., G.V. Varner, and B. Long. 2010. Registration of 'Santa Fe' pinto bean. J. Plant Registrations 4:12-16.

Kelly, J.D., G.V. Varner, and E.M. Wright. 2010. Registration of 'Bellagio' cranberry bean. J. Plant Registrations 4: 171-174.

Los Comités de Investigación Agrícola Local (CIALS) en Los Valles de Los Ríos Chota y Mira (Imbabura y Carchi), Ecuador: Avances y Retos. Boletín Divulgativo. Agosto 2008. Mejore su nutrición, salud y alimentación...Consuma Fréjol. Hoja Divulgativa.

Mejía, P.Z., M.Pavon and J.C. Rosas. 2011. Avances en la producción orgánica de frijol en la región del Lago Yojoa, Honduras. Presentation made at the LVI PCCMCA Annual Meeting, April 25-29, Sonsonate, El Salvador.

Mkwaila, W., and J. D. Kelly. 2011. Heritability estimates and phenotypic correlations for white mold resistance and agronomic traits in pinto bean. Annu. Rep. Bean Improv. Coop. 54:134-135.

Muchero, W., N.N. Diop, P.R. Bhat, R.D. Fenton, S. Wanamaker, M. Pottorff, S. Hearne, N. Cisse, C. Fatokun, J.D. Ehlers, P.A. Roberts, and T.J. Close. 2009d. A consensus genetic map of cowpea [Vigna unguiculata (L) Walp.] and synteny based on EST-derived SNPs. Proceedings of the National Academy of Sciences, USA 106:18159-18164.

Musoni, A., L. Butare, D. M.nkubana, E. Gasigwa, F. Nsanzabera, M. Blair, and R. Buruchara. 2009. Climbing beans for increased productivity: Participatory selection of new varieties adapted in semi-arid regions in Rwanda. In Proceedings of International Conference on Program for African Seed Systems. Alliance for a Green Revolution in Africa (AGRA). Bamaako, Mali. October, 2009.

Roman-Avilés, B., J.M. Lewis and J.D. Kelly. 2011. Fusarium Genetic Control: A Long Term Strategy. In: Control of Fusarium Diseases, In Editors: Fernando M. Alves-Santos and Julio J. Diez. Control of Fusarium Diseases. 2011:000-000 ISBN: 978-81-308-0470-5.

Rosas JC, Araya R, Ortega I. 2009. Variedades de Frijol Rojo obtenidas por Fitomejoramiento Participativo en Honduras y Nicaragua. Est. Exp. Agr. Fabio Baudrit Moreno, Heredia, Costa Rica, 40p.

Rosas JC, Guachambala MS, Ramos RA. 2010. Guía ilustrada para la Descripción de las Características de Variedades de Frijol Común. EAP, Zamorano, Honduras, 22p.

Ruiz L, Beaver JS, Rosas JC, Ernest E. 2010. Evaluation of Lima bean landraces from Puerto Rico. Ann. Rep. of the Bean Improvement Coop. 53:72-73.

Singh, S.P., H. Terán and J.S. Beaver. 2009. Scarlet runner bean germplasm accessions G 35006 and G 35172 possess resistance to multiple diseases of common bean. Ann. Rep. of the Bean Improv. Coop. 52:22-23.

II. INTEGRATED CROP MANAGEMENT

A. Refereed Journal Articles

A.N. Pell. 2008. Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. Ecosystems 11: 726–739.

Agunbiade, T.A., B. S. Coates, D. Forgacs, V. M. Margam, L. L. Murdock, M. N. Ba, C. L. Binso-Dabire,

Ba, N.M., Margam V. M., Dabire-Binso C. L., Sanon A., McNeil J., Murdock, L.L. and B. R. Pittendrigh. 2009. Seasonal and regional distribution of the cowpea pod borer, Maruca vitrata Fabricius (Lepidoptera: Crambidae), in Burkina Faso. International Journal of Tropical Insect Science, 29(3). 29(3): 109-113.

Baoua, I., Ba, M., Dabire, C., Tamò, M., Ishiyaku, M. Margam, V., and B.R. Pittendrigh. Infestations of insect pests on cultivated cowpeas in Niger, Burkina Faso, and Northern Nigeria. International Journal of Tropical Insect Science. In press.

Baoua, I., N. M. Ba, T. A. Agunbiade, V. Margam, C. L. Binso-Dabiré, S. Antoine, and B. R. Pittendrigh. 2011. Potential use of Sesbania pachyca DC (Fabaceae: Papilionoideae) as a refugia for the legume pod borer, Maruca vitrata Fabricius (Lepidoptera: Crambidae). International Journal of Tropical Insect Science 31 (4): 212-218.

Bello-Bravo, J., Diaz, R., Venugopal, S., Viswanathan, M., and B. R. Pittendrigh. 2010. Expanding the impact of practical scientific concepts for low-literate learners through an inclusive and participatory virtual knowledge ecosystem. Journal of the World Universities Forum. 3(4):147-164.

Bello-Bravo, J., F. Seufferheld, L. D. Steele, T. Agunbiade, D. Guillot, G. Cutz, & B. R. Pittendrigh. 2011. Scientific Animations without Borders: an international online approach for building applicable scientific educational materials for use on cell phones, portable devices, and the Internet in developing nations. The International Journal of Science in Society. 2.4: 49-62.

Blair M.W., A.C. Fernandez, F. Pedraza, M.C. Muñoz-Torres, N. Sella Kapu, K.M. Brown, J.P. Lynch. 2011. Parallel sequencing of ESTs from two cDNA libraries for high and low phosphorus adaptation in common beans. The Plant Genome 4 (3): 1-14.

Burton A.L., M Williams, J.P. Lynch, K.M. Brown. 2012. RootScan: Software for high-throughput analysis of root anatomical traits. Plant and Soil 357 (1-2): 189-203.

Butler, L.M. & R.E. Mazur. 2007. "Principles and Processes for Enhancing Sustainable Rural Livelihoods: Collaborative Learning in Uganda" International Journal of Sustainable Development & World Ecology 14(6):604-617.

Cevdet and, Gökgöz. 2007. Effects of traditional cooking methods on some antinutrients and in vitro protein digestibility of dry bean varieties (Phaseolus vulgaris L.) grown in Turkey. International Journal of Food Science & Technology 42 (7), 868–873.

Dannon, E., Tamò, M., Huis, A., Dicke, M. 2010. Functional response and life history parameters of Apanteles taragamae, a larval parasitoid of Maruca vitrata. BioControl, 55: 363-378.

Dannon, E., Tamò, M., Huis, A., Dicke, M., 2010. Effects of volatiles from Maruca vitrata larvae and caterpillar-infested flowers of their host plant Vigna unguiculata on the foraging behavior of the parasitoid Apanteles taragamae. J Chem Ecol. 2010 Oct; 36(10):1083-91. Epub 2010 Sep 15.

Ganyo, K.K., Tounou, A.K., Agboton, C., Dannon, E.A., Pittendrigh, B.R., and M. Tamo. 2012. Interactions between the aphid parasitoid Lysiphlebus testaceipes Cresson (Hymenoptera: Aphidiidae) and its hyperparasitoid Syrphophagus africanus Gahan (Hymenoptera: Encyrtidae). International Journal of Tropical Insect Science 32 (1).

Gassmann, A.J., Onstad D. W. and B. R. Pittendrigh. 2009. Evolutionary Analysis of Herbivorous Insects in Natural and Agricultural Environments. Pest Manag. Sci. 65(11): 1174 – 1181.

Geographic distribution of phylogenetically-distinct legume pod borer, Maruca vitrata (Lepidoptera: Pyraloidea: Crambidae). Molecular Biology Reports. 38(2): 893-903.

Henry, A, JC Rosas, JS Beaver, JP Lynch. 2010. Root architectural multilines: effects on resource acquisition under stress and belowground competition. Field Crops Research, 117:209-218.

Henry, A, NF Chaves, PJA Kleinman, JP Lynch. 2010. Will nutrient-efficient genotypes mine the soil? Effects of genetic differences in root architecture in common bean (Phaseolus vulgaris, L.) on soil phosphorus depletion in a low-input agro-ecosystem in Central America. Field Crops Research, 115.1: 67-68.

Henry, A, P Kleinman, JP Lynch. 2009. Phosphorus runoff from a phosphorus deficient soil under common bean (Phaseolus vulgaris L.) and soybean (Glycine max L.) genotypes with contrasting root architecture. Plant and Soil 317:1-16.

I. Baoua, M. F. Ishiyaku, M. Tamò, B. R. Pittendrigh. The spatial genetic differentiation of the legume pod borer, Maruca vitrata F. (Lepidoptera: Pyralidae) populations in West Africa. Bulletin of Entomological Research. 102(5):589-599.

International Center for Tropical Agriculture (CIAT). 2008. "The impact of improved bush bean varieties in Uganda." Highlights - CIAT in Africa. No. 43. Kampala, Uganda.

International Journal of Tropical Insect Science 30: 108-114.

Kimetu, J.M., J. Lehmann, S.O. Ngoze, D.N. Mugendi, J.M. Kinyangi, S. Riha, L. Verchot, J.W. Recha and

L.L. Murdock, and B. R. Pittendrigh. 2011. Transcriptome sequencing, and rapid development and application of SNP markers for the legume pod borer Maruca vitrata (Lepidoptera: Crambidae). PLoS One. 6(7): e21388.

Lukac RJ, Aluru MR, Reddy MB. 2009. Quantification of ferritin from staple food crops. J Agric Food Chem. 57:2155-61.

Lynch, J.P. 2011. Root phenes for enhanced soil exploration and phosphorus acquisition: tools for future crops. Plant Physiology, 156:1041-1049.

Margam V. M., Coates B., Ba N.M., Dabire-Binso C., Baoua I., Tamò M. Ishiyaku M. F. and B. R. Pittendrigh. 2009. Maruca vitrata Fabricius (lepidoptera: pyraloidea: crambidae) mitochondrial genome. PLoS One.

Margam V. M., Coates B., Ba N.M., Dabire-Binso C., Tamò M., Pittendrigh B. R. and L. L. Murdock. 2009. Geographical variation revealed by molecular barcoding of the legume pod borer, Maruca vitrata (Lepidoptera: Pyraloidea: Crambidae). Molecular Biology Reports. Online First Release.

Margam, V. M. I. Baoua, N. M. Ba, Ishiyaku, M. F., Huesing, J. E., Pittendrigh, B. R., and L. L. Murdock. 2010. Wild host plants of legume pod borer Maruca vitrata (lepidoptera: pyraloidea: crambidae) in southern Niger and northern Nigeria – implications for insect resistance management strategies.

Margam, V., B. S. Coates, R. L. Hellmich, T. Agunbiade, M. J. Seufferheld, W. Sun, M. N. Ba, A. Sanon, C. L. Binso-Dabire, I. Baoua, M. F. Ishiyaku, F. G. Covas, R. Srinivasan, J. Armstrong, L. L. Murdock, and B. R. Pittendrigh. 2011. Mitochondrial genome sequence and expression profiling for the legume pod borer Maruca vitrata (Lepidoptera: Crambidae). PLoS One. 6(2): e16444.

Margam, V.M., Baoua, I., Ba, N.M., Ishiyaku, M.F., Huesing, J.E., Pittendrigh, B.R., & Murdock, L.L. 2010. Wild host plants of legume pod borer Maruca vitrata (Lepidoptera: Pyraloidea: Crambidae) in southern Niger and northern Nigeria. International Journal of Tropical Insect Science, 30(2): 108-114.

Margam, V.M., Coates, B.S., Ba, M.N., Sun, W., Binso-Dabire, C.L., Baoua, I., Ishiyaku, M.F., Shukle, J.T., Hellmich, R.L., Covas, F.G., Ramasamy, S., Armstrong, J., B. R. Pittendrigh, & Murdock, L.L. 2011.

Margam,V.M., B.S. Coates, D. O. Bayles, R.L. Hellmich, T. Agunbiade, M.J. Seufferheld, W. Sun, J.A. Kroemer, M.N. Ba, C.L. Binso-Dabire, I.B. Bokary, M.F. Ishiyaku, F.G. Covas, R. Srinivasan, J. Armstrong,

Medvecky, B.A. and Q.M. Ketterings. 2009. Incorporation of legume residues does not increase productivity of intercropped beans on smallholder farms in Trans Nzoia district, Kenya. Biological Agriculture and Horticulture 26(4).

Nord, E.A, K. Shea, J.P. Lynch. 2011. Optimizing reproductive phenology in a two-resource world: a dynamic allocation model of plant growth predicts later reproduction in phosphorus limited plants. Annals of Botany, doi: 10.1093/aob/mcr143.

Nord, EA, JP Lynch. 2009. Plant phenology: a critical controller of soil resource acquisition. Journal of Experimental Botany, 60:1927-1937; doi:10.1093/jxb/erp018

Onstad D. W., Kang J., Ba N. M., Dabire C., Tamò M., Jackai, L. and B. R. Pittendrigh. Modeling Evolution of Resistance by Maruca vitrata to transgenic insecticidal cowpea in Africa. Environmental Ecology 41(5): 1255-1267.

Postma, JA, JP Lynch. 2010. Theoretical evidence for the functional benefit of root cortical aerenchyma in soils with low phosphorus availability. Annals of Botany, doi: 10.1093/aob/mcq199.

Richardson A.E., J.P. Lynch, P.R. Ryan, E. Delhaize, F.A. Smith, S.E. Smith, P.R. Harvey, M.H. Ryan, E.J. Veneklaas, H. Lambers, A. Oberson, R.A. Culvenor, R.J. Simpson. 2011. Plant and microbial strategies to improve the phosphorus efficiency of agriculture. Plant and Soil 349: 121-156.

Sanon, A.,Ba, N.M., Dabire-Binso C. L. and Pittendrigh, B. R. 2010. Effectiveness of Spinosad (Naturalytes) in controlling the cowpea storage pest, Callosobruchus maculatus (F.) (Coleoptera: Bruchidae). J. Econ. Entom. 103(1): 203-210.

Simpson R.J., Oberson A., Culvenor R.A., Ryan M.H., Veneklaas E.J., Lambers H., Lynch J.P., Ryan P.R., Delhaize E., Smith F.A., Smith S.E., Harvey P.R., Richardson A.E. 2011. Strategies and agronomic interventions to improve the phosphorus-use efficiency of farming systems. Plant Soil 12(1):121-156.

Smith, R.A., & Findeis, J.L. 2013. Explaining audience segmentation: investigating adopter categories to diffuse an innovation to prevent famine in rural Mozambique. Journal of Health Communication 18(1).

Smith, R.A., Barclay, V.C., & Findeis, J.L. 2011. Investigating preferences for mosquito-control technologies in Mozambique with latent class analysis. Malaria Journal, 10:200, doi:10.1186/1475-2875- 10-200.

Sseguya, H., Mazur, R. E. and Masinde, D. M. 2009. Harnessing Community Capitals for Livelihood Enhancement: Experiences from a Livelihood Program in Rural Uganda. Community Development 40:123-138.

B. Book Chapters

Pittendrigh, B.R., Sun L., Gaffney P., and J. Huesing. 2008. "Negative Cross Resistance", In: Insect Resistance Management. Ed. David Onstad. p. 108-124.

C. Other Publications

(reports, conference papers, working papers, manuals, etc.)

Adati, T., Tamò, M., Downham, M.C.A. 2010. Migration and mating status of the legume pod borer, Maruca vitrata in Northern Nigeria with reference to the efficacy of synthetic sex pheromone traps. In: Tamò M., Fatokun, C., Boukar, O., Coulibaly, O. and Muranaka, S (eds.). Improving livelihoods in the cowpea value chain through advancements in science. Proceedings of the 5th World Cowpea Research Conference, 26 September – 1 October 2010, Saly, Senegal .

Agunbiade, T., L. Steele, B. Coates, A. Gassmann, V. Margam, M. Ba, C. Dabiré-Binso, I. Baoua, J. Bello- Bravo, F. Seufferheld, and B. Pittendrigh. 2010. IPM-omics: from genomics to extension for integrated pest management of cowpea. In: Tamò M., Fatokun, C., Boukar, O., Coulibaly, O. and Muranaka, S (eds.). Improving livelihoods in the cowpea value chain through advancements in science. Proceedings of the 5th World Cowpea Research Conference, 26 September – 1 October 2010 Saly, Senegal.

Bello Bravo, J., Seufferheld, F., Ba, M., Binso-Dabire, C.L., Baoua, I., Tamò, M., Pittendrigh, B. 2010. Plant protection deployment strategies for extension services and cowpea farmers. Paper presented at the 5th World Cowpea Research Conference, Saly, Senegal, Sept 27-Oct 2, 2010.

Bello-Bravo, J., F. Seufferheld, T. Agunbiade, L. Steele, D. Guillot, M. N. Ba, C. L. Binso-Dabire, I. Baoua, M. N'Diaye, M. Tamò and B. Pittendrigh. 2010. Scientific Animations Without Borders: cell-phone videos for cowpea farmers. In: Tamò M., Fatokun, C., Boukar, O., Coulibaly, O. and Muranaka, S (eds.). Improving livelihoods in the cowpea value chain through advancements in science. Proceedings of the 5th World Cowpea Research Conference, 26 September – 1 October 2010 Saly, Senegal.

Dabiré, C., Tamò, M. Ouédraogo, T.J., Tignegré, J. B., Ba, M., Hammond, W. Coulibaly, O. 2010. Efforts de gestion des contraintes biotiques au Burkina Faso et en Afrique de l'Ouest. Paper presented at the 5th World Cowpea Research Conference, Saly, Senegal, Sept 27-Oct 2, 2010.

Findeis, J.L., & Smith, R.A. 2011. Diffusion of technologies: Economic and social networks, and policy in rural Mozambique. Paper presented at the Max Planck Institute of Economics, Jena, Germany, February 18-19.

Huesing, J., Romeis, J., Ellstrand, N., Raybould, A., Hellmich, R., Wolt, J., Ehlers, J., Margam, V., Pasquet, R., Stein, J., Tamò, M., B. R. Pittendrigh, Fatokun, C., Hokanson, K., Ishiyaku, M., Matole, M., Mignouna, J., Moar, W., Nangayo, F., Ouedraogo, J., Schaal, B., and Murdock, L. June 2011. Regulatory considerations surrounding the deployment of Bt-expressing cowpea in Africa: report of the deliberations of an expert panel. GM Crops 1.2.

Huesing, J., Romeis, J., Tamò, M. 2010. Assessment of potential impact of Bt-cowpea on non-target organisms. Paper presented at the 5th World Cowpea Research Conference, Saly, Senegal, Sept 27-Oct 2, 2010.

St.Clair, SB, JP Lynch. 2010. The opening of Pandora's box: climate change impacts on soil fertility and crop nutrition in developing countries. Plant and Soil, DOI 10.1007/s11104-010-0328-z.

VEDCO. 2010. Annual Report 2009. Kampala, Uganda: Volunteer Efforts for Development Concerns.

III. NUTRITIONAL AND HEALTH

A. Refereed Journal Articles

Abdulkadir A.E., Sohani S.A., and Agoi, F. 2009. The dilemma of over- and under- nutrition coexistence among western Kenya children. AJFAND, 9: 962-974.

Chintharlapalli, S., Papineni, S., Abdelrahim, M., Abudayyeh, A., Jutooru, I., Chadalapaka, G., Wu, F., Mertens-Talcott, S., Vanderlaag, K., Cho, S.D., et al. 2009. Oncogenic microRNA-27a is a target for anticancer agent methyl 2-cyano-3,11-dioxo-18beta-olean-1,12-dien-30-oate in colon cancer cells. Int J Cancer 125: 1965-1974.

Christensen, D.L., Eis, J., Hansen, A.W., Larsson, M.W., Mwaniki, D.L., Kilonzo, B., Tetens, I., Boit, M.K., Kaduka, L., Borch-Johnsen, K., et al. 2008. Obesity and regional fat distribution in Kenyan populations: Impact of ethnicity and urbanization. Annals of Human Biology 35: 232-249.

Frota, K.M.G., Mendonca, S., Saldiva, P.H.N., Cruz, R.J., Areas, J.A.G. 2008. Cholesterol-lowering properties of whole cowpea seed and its protein isolate in hamsters. J. Food Sci. 73: H235-H240.

Ha, T.J., Lee, M.-H., Jeong, Y.N., Lee, J.H., Han, S.-I., Park, C.-H., Pae, S.-B., Hwang, C.-D., Baek, I.-Y., and Katona, P. and J. Katona-Apte. 2008. The interaction between nutrition and infection. Clinical Infectious Diseases, 46(10): 1582-1588.

Meng, Q., Velalar, C.N., and Ruan, R. 2008. Effects of epigallocatechin-3-gallate on mitochondrial integrity and antioxidative enzyme activity in the aging process of human fibroblast. Free Radical Biology and Medicine, 44: 1032-1041.

Park, K.-Y. 2010. Anthocyanins in cowpeas [Vigna unguiculata (L.) Walp. ssp. unguiculata]. Food Science and Biotechnology, 19: 821-826.

Soohyoung, L., Young-Jin, K., Sanghoon, K., Younghee, L., Soo, Y.C., Jinseu, P., and Hyung-Joo, K. 2009. Inhibitory effects of flavonoids on TNF-α-induced IL-8 gene expression in HEK 293 cells. BMB Report 42: 265–270.

B. Other Publications

(reports, conference papers, working papers, manuals, etc.)

Colecraft, E., 2008. HIV/AIDS: nutritional implications and impact on human development. Proceedings Of The Nutrition Society, 67: 109-113.

Fergusson, P. and A. Tomkins. 2009. HIV prevalence and mortality among children undergoing treatment for severe acute malnutrition in sub-Saharan Africa: a systematic review and meta-analysis. Transactions of the Royal Society of Tropical Medicine and Hygiene, 103(6): 541-548.

Mazur RE, Musoke H, Nakimbugwe D, Ugen M. 2011. "Enhancing Nutritional Value and Marketability of Beans through Research and Strengthening Key Value Chain Stakeholders in Uganda." Conference Note 1 for International Conference on 'Leveraging Agriculture for Improving Nutrition and Health' in New Delhi. Washington, DC: International Food Policy Research Institute.

Mazur RE. 2011. "Value Chains - How Can They Achieve Food and Nutrition Security Goals?" West Africa CAADP Nutrition Program Development Workshop. Dakar, Senegal. Nov. 9-12.

Vasanthakaalam H. 2011. The Cold Extrusion Process. in Adding Value to Grains – Science, Nutrition and Technology, 109-11. Germany: Lambert Academic Publishing, 188 pages. ISBN-10: 3845438479, ISBN-13: 978-3845438474.

VEDCO. 2011. Annual Report 2010. Kampala, Uganda: Volunteer Efforts for Development Concerns.

IV. VALUE CHAIN

A. Other Publications

(reports, conference papers, working papers, manuals, etc.)

Chachomba, Isabel. 19/04/2011. Report on Marketing of Common beans in Bazuka Market (Comercialização de Feijões no Mercado Basuka). Ministry of agriculture, Mozambique.

Chilundika, Natasha. 2011. Market Participation of Bean Smallholder Farmers in Zambia: A Gender-Based Approach, B.Sc. Thesis, Dept. of Agric Economics, Univ. of Zambia.

Chiona, Susan. 2011. Technical and Allocative Efficiency of Smallholder Maize Farmers in Zambia, M.Sc. Thesis, Department of Agric Economics, University of Zambia.

Myece, Agness. 2011. Factors Influencing Cowpea Producers' Choice of Marketing Channels In Zambia, B.Sc. Thesis, Dept. of Agric Economics, Univ. of Zambia.

Ngoma, Edna. 2011. Supply Chain Participation of Cowpea Producers in Zambia, B.Sc. Thesis, Department of Agricultural Economics, University of Zambia.

Samboko, Chimuka. 2011. An Assessment of Factors Influencing the Profitability of Bean Production in Zambian, B.Sc. Thesis, Dept. of Agric Economics, Univ. of Zambia.

Sunga, Chalwe. 2011. Market Information in the Bean and Cowpea Supply Chain in Zambia, B.Sc. Thesis, Department of Agricultural Economics, University of Zambia.

Zulu, Esther. 2011. Profitability of Smallholder Cowpea Production in Zambia, B.Sc. Thesis, Department of Agricultural Economics, University of Zambia.

V. IMPACT ASSSESSMENT

A. Other Publications

(reports, conference papers, working papers, manuals, etc.)

Magen, B. 2012. An Ex Post Economic Impact Assessment of Bean/ Cowpea CRSP Investment on Varietal Development in Senegal. Plan B paper towards M.S. degree. Department of Agricultural, Food and Resource Economics, Michigan State University.

Moussa, B.; Lowenberg-DeBoer, J.; Fulton, J.; and Boys, K. Farmers in West and Central Africa obtain economic benefits from enhanced cowpea storage technologies. Impact Assessment Research Brief No. 3, July 2012. (English version available)

Reyes, B. 2012. The Economic Impact of Improved Bean Varieties and Determinants of Market Participation: Evidence from Latin America and Angola. Ph.D. Dissertation. Michigan State University. 203 pp.

Reyes, B.; Bernsten, R.; and Maredia, M. Sustaining a steady flow of high yielding, improved bean varieties through the bean research network in Central America. Impact Assessment Research Brief No. 2, July 2012. (English and Spanish versions available)

Reyes, B.; Maredia, M.; and Bernsten, R. Improved bean varieties in Central America and Ecuador generate economic benefits to farmers. Impact Assessment Research Brief No. 1, July 2012. (English and Spanish versions available)

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I. STRATEGIC OBJECTIVE ONE: Advancing the Productivity Frontier for Grain Legumes

Research output from LIL Projects SO1.A1, SO1.A2, SO1.A3, SO1.A5, SO1.B1

A. Refereed Journal Articles

Agunbiade, T. A., B. S. Coates, W. L. Sun, M. R. Tsai, M. C. Valero, M. Tamo and B. R. Pittendrigh. 2017. Comparison of the mitochondrial genomes of the Old and New World strains of the legume pod borer, *Maruca vitrata* (Lepidoptera: Crambidae). *International Journal of Tropical Insect Science* 37(3): 125-136.

Agunbiade, T.A., B.S. Coates, B. Datinon, R. Djouaka, M.-R. Tsai, W. Sun, M. Tamò, and B. R. Pittendrigh. 2014. Genetic differentiation among *Maruca vitrata* F. (Lepidoptera: Crambidae) populations on cultivated cowpea and wild host plants: Implications for insect resistance management and biological control strategies. *PLoS ONE* 9(3): e92072. DOI: 10.1371/journal.pone.0092072

Agunbiade, T.A., W. Sun, B. S. Coates, R. Djouaka, M. Tamo, M. N. Ba, C. Binso-Dabire, I. Baoua, B. P. Olds, and B.R. Pittendrigh. 2013. Development of reference transcriptomes for the major insect pests of cowpea: A toolbox for insect pest management approaches in West Africa. *PLoS ONE*, 8(11): e79929. DOI: 10.1371/journal.pone.0079929

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

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

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

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

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

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

Beaver, J.S., E.H. Prophete, J.C. Rosas, G. Godoy Lutz, J.R. Steadman and T.G. Porch. 2014. Release of 'XRAV-40-4' black bean (*Phaseolus vulgari*s L.) cultivar. *J. Agric. of the Univ. of Puerto Rico* 98:83–87.

Beaver, J.S., J.C. Rosas, T.G. Porch, M.A. Pastor-Corrales, G. Godoy-Lutz and E.H. Prophete. 2015. Registration of PR0806-80 and PR0806-81 white bean germplasm with resistance to BGYMV, BCMV, BCMNV, and rust. *J. Plant Reg.* 9:208–211. DOI: 10.3198/jpr2014.09.0061crg

Belko, N., Cisse, N., Diop, N.N., Zombre, G., Thiaw, S., Satoru Muranaka, S., Ehlers, J.D. 2014. Selection for postflowering drought resistance in short- and medium- duration cowpeas using stress tolerance indices. *Crop Science* 54:1–9. DOI: 10.2135/CropSci2012.12.0685

Bello, M. H., S. M. Moghaddam, M. Massoudi, P. E. McClean, P. B. Cregan, and P. N. Miklas. 2014. Application of in silico bulked segregant analysis for rapid development of markers linked to bean common mosaic virus resistance in common bean. *BMC Genomics* 15:903. DOI: 10.1186/1471-2164-15-903

Bello-Bravo, J., and B.R. Pittendrigh. 2014. Scientific Animations Without Borders: Entomological origins and cross-discipline impact. *Entomology Society of Canada Bulletin*, 46(1): 31–36.

Bello-Bravo, J., T. Agunbiade, E. Dannon, M. Tamo, and B.R. Pittendrigh. 2013. The prospect of animated videos in agriculture and health: A case study in Benin. *Int'l Journal of Education and Development Using ICT*, 9(3): 4–16.

Bello-Bravo, J., Tamò, M., Dannon, E. A. and B. R. Pittendrigh. 2017. An assessment of learning gains from educational animated videos versus traditional extension presentations among farmers in Benin. *Information Technology for Development*, 1-21, DOI:10.1080/02681102.2017.1298077

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

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

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

Burt, A.J., H. M. William, G. Perry, R. Khanal, K. P. Pauls, J. D. Kelly, A. Navabi. 2015. Candidate gene identification with SNP marker-based fine mapping of anthracnose resistance gene *Co-4* in common bean. *PLoS ONE* 10(10): e0139450. DOI:10.1371/journal.pone.0139450.

Cichy, K.A., A. Fernandez, A. Kilian, J.D. Kelly, C.H. Galeano, S. Shaw, M. Brick, D. Hodkinson, and E. Troxtell. 2014. QTL analysis of canning quality and color retention in black beans (*Phaseolus vulgari*s L.). *Molecular Breeding* 33:139–154. DOI: 10.1007/s11032-013-9940-y. DOI: 10.1007/s11032-013-9940-y

Cichy, K.A., T.G. Porch, J.S. Beaver, P. Cregan, D. Fourie, R. Glahn, M.A. Grusak, K. Kamfwa, D.N. Katuuramu, P. McClean, E. Mndolwa, S. Nchimbi-Msolla, M.A. Pastor-Corrales and P.N. Miklas. 2015. A *Phaseolus vulgaris* diversity panel for Andean bean improvement. *Crop Sci.* 55:2149–2160. DOI: 10.2135/cropsci2014.09.0653

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

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

Hoyos-Villegas, V., W. Mkwaila, P.B. Cregan and J.D. Kelly. 2015. QTL analysis of white mold avoidance in pinto bean (*Phaseolus vulgariLs*). *Crop Sci*. 55:2116–2129. DOI:10.2135/cropsci2015.02.0106

Humphries, S., J.C. Rosas and M. Gomez. 2016. A farmer NGO-scientist synergy in Honduras. *Farming Matters*, Wageningen, The Netherlands 32 (1):14-16.

Huynh, B.L., Close, T.J., Roberts, P.A., Cisse, N., Drabo, I., Boukar, O., Lucas, M.R., Wanamaker, S., Pottorff, M., Ehlers, J.D. 2013. Gene pools and the genetic architecture of domesticated cowpea. *The Plant Genome* 6:1–8. DOI: 10.3835/plantgenome2013.03.0005

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

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

Huynh, B.L., Matthews, W.C., Ehlers, J.D., Lucas, M.R., Santos, J.R.P., Ndeve, A., Close, T.J., Roberts, P.A. 2015. A major QTL corresponding to the *Rk* locus for resistance to root-knot nematodes in cowpea (*Vigna unguiculata* L. Walp.). *Theoretical and Applied Genetics* 129(1):87-95. DOI: 10.1007/s00122-015-2611-0.

Ihm, J., M. Pena-Y-Lillo, K. Cooper, Y. Atouba, M. Shumate, J. Bello-Bravo, M. Ba, C. Dabire-Binso, and B. Pittendrigh. 2015. The case for a two-step approach to agricultural campaign design. *Journal of Agricultural & Food Information*, 16: 203–220.

Ihm, J., M. Shumate, J. Bello-Bravo, N. Ba, C. Dabire-Binso, and B. Pittendrigh. 2014. Variance of cognitive social structures between farmers and extension agents in Burkina Faso. VOLUNTAS: *International Journal of Voluntary and Nonprofit Organizations*, 25(5): 1769-1785. DOI: 10.1007/s11266-014-9515-5.

Isaacs, K.B., S.S. Snapp, J.D. Kelly and K. Chung. 2016. Farmer knowledge identifies a competitive bean ideotype for maize–bean intercrop systems in Rwanda. *Agriculture & Food Security 5* (15).

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

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

Kamfwa, K., K.A. Cichy and J.D. Kelly. 2015. Genome-wide association analysis of symbiotic nitrogen fixation in common bean. *Theor. Appl. Genet.* 128:1999–2017. DOI: 10.1007/s00122-015-2562-5.

Kamfwa, K., K.A. Cichy and J.D. Kelly. 2015. Genome-wide association study of agronomic traits in common bean. *The Plant Genome* 8. DOI:10.3835/plantgenome2014.09.0059.

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

Kelly, J.D., G.V. Varner, K.A. Cichy, and E.M. Wright. 2014. Registration of “Powderhorn” great northern bean. *J. Plant Registrations* 8:1–4. DOI:10.3198/jpr2013.05.0020crc.

Kelly, J.D., G.V. Varner, K.A. Cichy, and E.M. Wright. 2015. Registration of ‘Alpena’ navy bean. *J. Plant Registrations* 9:10-14. DOI:10.3198/jpr2014.04.0025crc.

Kelly, J.D., G.V. Varner, K.A. Cichy, and E.M. Wright. 2015. Registration of ‘Zenith’ black bean. *J. Plant Registrations* 9:15–20. DOI:10.3198/jpr2014.05.0035crc.

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

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

Kelly, J.D., G.V. Varner, S. Hooper, K.A. Cichy, and E.M. Wright. 2016. Registration of ‘Samurai’ otebo bean. *J. Plant Registrations*, March 4, 2016. DOI:10.3198/jpr2015.09.0051crc.

Kelly, J.D., J. Trapp, P.N. Miklas, K.A. Cichy, and E.M. Wright. 2015. Registration of ‘Desert Song’ Flor de Junio and ‘Gypsy Rose’ Flor de Mayo common bean cultivars. *J. Plant Registrations* 9:133–137. DOI:10.3198/jpr2014.05.0028crc.

Khankhum S., Valverde, R., Pastor-Corrales, M., Osorno, J.M., and Sabanadzovic, S. 2014. Two endornaviruses show differential infection patterns between gene pools of *Phaseolus vulgaris. Arch. Virol*. 160:1131–1137. DOI: 10.1007/s00705-015-2335-0

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

Kusolwa P.M, J.R. Myers, T.G. Porch, Y. Trukhina, A. González-Vélez and J.S. Beaver. 2016. Registration of AO-1012-29-3-3A Red Kidney Bean Germplasm Line with Bean Weevil, BCMV, and BCMNV Resistance. *Journal of Plant Registrations* 10:149-153. doi:10.3198/jpr2015.10.0064crg

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

Lucas, M.R., Huynh, B., Ehlers, J.D., Roberts, P.A., Close, T.J. 2013. High-resolution SNP genotyping reveals a significant problem among breeder resources. *The Plant Genome* 6:1–5.

Lucas, M.R., Huynh, B.L., Roberts, P.A., Close, T.J. 2015. Introgression of a rare haplotype from Southeastern Africa to breed California blackeyes with larger seeds. *Frontiers in Plant Science* 6:126. DOI: 10.3389/fpls.2015.00126.

Lucas, M.R., Huynh, B.L., Vinholes, P., Cisse, N., Drabo, I., Ehlers, J.D., Roberts, P.A., Close, T.J. 2013. Association studies and legume synteny reveal haplotypes determining seed size in Vigna unguiculata. *Frontiers in Plant Science* 4:95. pp. 1–9. DOI: 10.3389/fpls.2013.00095.

Mahamat-Hissene, H., Belko, N., Cisse, N., Sine, B., Ndoye, I. 2014. Amélioration de l’adaptation à la sécheresse chez le niébé (*Vigna unguiculata* L. Walpers). *Journal of Applied Biosciences* 77:6550–6563. DOI: 10.4314/jab.v77i0.12

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

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

Mendoza, F.A., K. A. Cichy, R. Lu, and J. D. Kelly. 2014. Evaluation of canning quality traits in black beans (*Phaseolus vulgaris* L.) by visible/near-infrared spectroscopy. *Food Bioprocess Technology*. DOI: 10.1007/s11947-014-1285-y.

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

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

Miklas, P.N, D. Fourie, B. Chaves, and C. Chirembe. 2017. Common bacterial blight resistance QTL BC420 and SU91 effect on seed yield, seed weight, and canning quality in dry bean. *Crop Sci*. 57:802-811.

Miklas, P.N., J. D. Kelly, J. R. Steadman and S. McCoy. 2014. Registration of partial white mold resistant pinto bean germplasm line USPT-WM-12. J. *Plant Registrations* 8:183–186.

Moghaddam, S.M., S. Mamidi, Q. Song, J.M. Osorno, R. Lee, P. Cregan, and P.E. McClean. 2013. Developing marker-class specific indel markers from next generation sequence data in *Phaseolus vulgaris. Frontiers in Plant Genetics and Genomics* 5:185.

Mukeshimana, G., A.L. Lasley, W.H. Loescher and J.D. Kelly. 2014. Identification of shoot traits related to drought tolerance in common bean seedlings. *J. Amer. Soc. Hort. Sci.* 139:299–309.

Mukeshimana, G., L. Butare, P.B. Cregan, M. W. Blair and J.D. Kelly. 2014. Quantitative trait loci associated with drought tolerance in common bean. *Crop Sci.* 54:923–938. DOI: 10.2135/cropsci2013.06.0427.

Mukeshimana, G., Y. Ma, A. E. Walworth, G-q. Song, and J.D. Kelly. 2013. Factors influencing regeneration and *Agrobacterium tumefaciens*-mediated transformation of common bean (*Phaseolus vulgaris L*.). *Plant Biotechnol*. Rep. 7:59–70. DOI: 10.1007/s11816-012-0237-0

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

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

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

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

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

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

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

Porch, T.G., Beaver, J.S., Abawi, G.A., Estevez de Jensen, C.E., Smith, J.R. 2014. Registration of a small-red dry bean germplasm, TARS-LFR1, with multiple disease resistance and superior performance in low nitrogen soils. *J. Plant Reg.* 8:177–182.

Porch, T.G., S. Valentin, C. Estevez de Jensen and J.S. Beaver. 2014. Identification of soil-borne pathogens in a common bean root rot nursery in Isabela, Puerto Rico. 2014. *J. of Agric. of the Univ. of Puerto Rico* 98:1–14.

Pottorff, M., Li, G., Ehlers, J.D., Close, T.J., Roberts, P.A. 2014. Genetic mapping, synteny, and physical location of two loci for *Fusarium oxysporum* f. sp. *tracheiphilum* race 4 resistance in cowpea [*Vigna unguiculata* (L.) Walp]. *Molecular Breeding* 33:779–791. DOI: 10.1007/s11032-013-9991-0

Prophete, E., G. Demosthenes, G. Godoy-Lutz, T.G. Porch, and J.S. Beaver. 2014. Registration of PR0633-10 and PR0737-1 red mottled dry bean germplasm lines with resistance to BGYMV, BCMV, BCMNV, and common bacterial blight. *J. Plant* Reg. 8:49–52.

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

Santos, J.R.P., Ndeve, A., Huynh, B.L., Matthews, W.C., Roberts, P.A. 2018. Transcriptome analysis of cowpea near-isogenic lines reveals candidate genes for root-knot nematode resistance. *PLoS* ONE

Schmutz J., McClean, P., Mamidi, S., Wu, G.A., Cannon, S.B., Grimwood, J., Jenkins, J., Shu, S., Song, Q., Chavarro, C., Torres-Torres, M., Geffroy, V., Moghaddam, S.M., Gao, D., Abernathy, B., Barry, K., Blair, M., Brick, M.A., Chovatia, M., Gepts, P., Goodstein, D.M., Gonzales, M., Hellsten, U., Hyten, D.L., Jia, G., Kelly, J.D., Kudma, D., Lee, R., Richard, M.M.S., Miklas, P.N., Osorno, J.M., Rodrigues, J., Thareau, V., Urrea, C.A., Want, M., Yu Y., Zhang, M., Wing, R.A., Cregan, P.B., Rokhsar, D.S., Jackson, S.A. 2014. A reference genome for common bean and genome-wide analysis of dual domestications. *Nature Genetics* 46:707–713. DOI: 10.1038/ng.3008

Sokame, B. M., A. K. Tounou, B. Datinon, E. A. Dannon Elie, C. Agboton, S. Ramasamy, B.R. Pittendrigh, and M. Tamò. 2014. Combined activity of the M*aruca vitrata* multi-nucleopolyhedrovirus, *Mavi*MNPV, and oil from neem, A*zadirachta indica* Juss and *Jatropha curcas* L., for the control of cowpea pests. *Crop Protection* 72: 150–157.

Song, Q., Jia, G., Hyten, D.L., Jenkins, J., Hwang, E.Y., Schroeder, S.G., Osorno, J.M., Schmutz, J., Jackson, S.A., McClean, P.E., and Cregan, P.B. 2015. SNP Assay Development for Linkage Map Construction, Anchoring Whole Genome Sequence and Other Genetic and Genomic Applications in Common Bean. G3: *Genes | Genomes| Genetics* 5(11):2285-90. DOI: 10.1534/g3.115.020594.

Souna, D.A., A. Bokonon-Ganta, M. Ravallec, A. Cusumano, B, R. Pittendrigh, A.-N. Volkoff, and M. Tamò. 2017. An insight in the reproductive biology of *Therophilus javanus* (Hymenoptera, Braconidae, Agathidinae), a potential biological control agent against the legume pod borer, (Lepidoptera, Crambidae). *Psyche*, Article ID 3156534, 8 pages, DOI:10.1155/2017/3156534.

Sousa, L.L., A. O. Gonçalves, M. C. Gonçalves-Vidigal, G. F. Lacanallo, A. C. Fernandez, H. Awale and J. D. Kelly. 2015. Genetic characterization and mapping of anthracnose resistance of Corinthiano common bean landrace cultivar. *Crop Sci.* 55:1900–1910. DOI:10.2135/cropsci2014.09.0604.

Steele, L. D., W. Sun, M. C. Valeroa, J. A. Ojo, K. M. Seong, B. S. Coates, V. M. Margam, M. Tamò and B. R. Pittendrigh. 2017. The mitogenome of the brown pod-sucking bug *Clavigralla tomentosicollis* Stäl (Hemiptera: Coreidae). *Agri Gene* 5: 27-36.

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

Tamò, M., Datinon, B., Dannon, E., Traore, F., Dabire, C., Pittendrigh, B. R. and R. Srinivasan. 2017. Towards successful establishment of exotic parasitoids attacking the pod borer *Maruca vitrata* in west Africa. *Biocontrol News and Information.* 38(2): 12-13.

Tock, A.J., D. Fourie, P.G. Walley, E.B. Holub, A. Soler, K.A. Cichy, M.A. Pastor-Corrales, Q. Song, T.G. Porch, J.P. Hart, R.C.C. Vasconcellos, J.G. Vicente, G.C. Barker and P.N. Miklas. 2017. Genome-wide linkage and association mapping of halo blight resistance in common bean to race 6 of the globally important bacterial pathogen. *Plant Sci.* 8:1170. DOI: 10.3389/fpls.2017.01170

Toffa Mehinto, J., Atachi, P., Douro, K., Dannon, E., Tamò, M. 2014 Mortality of *Maruca vitrata* (Lepidoptera: Crambidae) larval stages induced by different doses of the entomopathogenic fungi *Metarhizium anisopliae* and *Beauveria bassiana. International Journal of Advanced Research* 2: 273–285.

Toffa Mehinto, J., Atachi, P., Douro, K., Tamò, M. 2014. Pathogenicity of entomopathogenic fungi *Metarhizium anisopliae* and *Beauveria bassiana* on larvae of the legume pod borer *Maruca vitrata* (Lepidoptera: Crambidae). *ARPN Journal of Agricultural and Biological Science* 9: 55–56.

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

Traore, F., C.L. Dabire-Binso, N.M. Ba, A. Sanon and B.R. Pittendrigh. 2014. Annual cycles of the legume pod borer Maruca vitrata Fabricius (Lepidoptera: Crambidae) populations in southwestern Burkina Faso: Host-plants and natural enemies. *Arthropod–Plant Interactions*, 8(2): 155–162. DOI: 10.1007/s11829-014-9297-0

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

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

Valentín Torres, S., M.M. Vargas, G. Godoy-Lutz, T.G. Porch, and J.S. Beaver. 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.

Valero, M. C., J. A. Ojo, W. Sun, M. Tamò, B. S. Coates and B. R. Pittendrigh. 2017. The complete mitochondrial genome of *Anoplocnemis curvipes* F. (Coreinea, Coreidae, Heteroptera), a pest of fresh cowpea pods. *Mitochondrial DNA Part B* 2(2): 421-423.

Viteri, D. M., H. Terán, M. C. Asensio-S.-Manzanera, C. Asensio, T. G. Porch, P. N. Miklas, and S. P. Singh. 2014. Progress in breeding Andean common bean for resistance to common bacterial blight. *Crop Sci.* 54: 2084–2092. DOI: 10.2135/cropsci2014.03.0177

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

Wetro, E., A. K. Tounou, C. Agboton, B. Datinon, R. Srinivasan, B.R. Pittendrigh and M. Tamo. 2014. Bionomics of the parasitoid *Apanteles taragamae* as influenced by different diets fed to its host, *Maruca vitrata. BioControl* 59: 55–65.

B. Book Chapters

Boukar, O., Fatokun, C.A., Roberts, P.A., Abberton, M., Huynh, B.L., Close, T.J., Kyei-Boahen, S., Higgins T.J.V., Ehlers, J.D. 2015. Cowpea. In A. M. De Ron (Ed.) *Grain Legumes* (pp. 219–250). New York: Springer-Verlag.

Ferreira, J.J., A. Campa, and J.D. Kelly. 2013. Organization of genes conferring resistance to anthracnose in common bean. In R. K. Varshney and R. Tuberosa (Eds.), *Translational Genomics for Crop Breeding. Volume I: Biotic Stresses* (pp. 151–181). Ames, Iowa: Wiley Blackwell.

Huynh, B.L., Ehlers, J.D., Close, T.J., Cisse, N., Drabo, I., Boukar, O., Lucas, M.R., Wanamaker, S., Pottorff, M., Roberts, P.A. 2013. Enabling tools for modern breeding of cowpea for biotic stress resistance. In R. K. Varshney and R. Tuberosa (Eds.), *Translational Genomics for Crop Breeding. Volume I: Biotic Stresses.* (pp. 183–200). Ames, Iowa: Wiley-Blackwell.

Musoni, A., J. Kayumba, L. Butare, F. Mukamuhirwa, E. Murwanashyaka, D. Mukankubana, J.D. Kelly, J. Ininda, and D. Gahakwa. 2014. Innovations to overcome staking challenges to growing climbing beans by smallholders in Rwanda. In B. Vanlauwe et al. (Eds.), *Challenges and Opportunities for Agricultural Intensification of the Humid Highland Systems of Sub-Saharan Africa* (p. 129–136). Switzerland: Springer International Publishing. doi 10.1007/978-3-319-07662-1_11.

Osorno, J.M., and P.E. McClean. 2014. Common bean genomics and its applications in breeding programs. In S. Gupta, N. Nadarajan, and D.S. Gupta (Eds.), *Legumes in the Omic Era* (pp. 185–206). New York: Springer.

Vandemark, G.J., M.A. Brick, J.M. Osorno, J.D. Kelly, and C.A. Urrea. 2014. Edible Grain Legumes. In S. Smith, B. Diers, J. Specht, and B. Carver (Eds.), *Yield Gains in Major U.S. Field Crops* (p. 87–123). CSSA Special Pubs. 33. Madison, WI: American Society of Agronomy.

C. Other Publications

(reports, conference papers, working papers, manuals, etc.)

Agunbiade, T., Steele, L., Coates, B. S., Gassmann, A., Margam, V. M., Ba, M., Dabirí, C., Baoua, I., Bello-Bravo, J., Seufferheld, F., Sun, W., Tamò, M., Pittendrigh, B.R. 2013. IPM-omics: from genomics to extension for integrated pest management of cowpea. In Boukar, O., Coulibaly, O., Fatokun, C., Lopez, K., Tamò M. (Eds.). *Enhancing Cowpea Value Chains through Research Advances. Proceedings of the 5th World Cowpea Research Conference* (pp. 231–248), 26 September–1 October 2010. Saly: Senegal.

Batieno B.J., Tignegre J.B., Danquah E.Y., Drabo I., Close T.J., Roberts P.A., Huynh BL., Ouedraogo T.J., Ofori K., Ehlers J., 2016. Marker assisted backcrossing to improve cowpea for drought tolerance. 2016 Pan African Grain Legume and World Cowpea Conference, Zambia. DOI 10.13140/RG.2.2.31671.32166

Beaver, J.S., Prophete, E., Demóstenes, G. and T.G. Porch. 2015. Desarrollo de la Línea de Frijol Amarillo PR1146-138. Paper presented at the 2015 meeting of the PCCMCA (Generación de tecnología para la innovación de la agricultura intensiva sostenible) held in Guatemala City, 4–7 May 2015.

Bello, J., Seufferheld, F., Steele, L. D., Agunbiade, T., Guillot, D., Cutz, G., Pittendrigh, B.R. 2013. Scientific Animations without Borders: an international collaborative approach for building applicable scientific educational materials for use on cell phones, and the Internet in developing nations. In Boukar, O., Coulibaly, O., Fatokun, C., Lopez, K., Tamò , M. (Eds.). *Enhancing cowpea Value Chains through Research Advances. Proceedings of the 5th World Cowpea Research Conference* (pp. 369–380), 26 September–1 October 2010, in Saly, Senegal.

Bornowski, N., F. A. Mendoza, and J. D. Kelly. 2017. Mapping and predicting color retention and other quality traits in black bean populations. A*nn. Rep. Bean Improv. Coop.* 60:151-152.

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

Porch, T.G., J.S. Beaver, S. Colom, A. Vargas, Y. Trukhina, and C. Estevez de Jensen. 2014. Development of tools for *Macrophomina phaseolina* evaluation and for genetic improvement of common bean. *Ann. Rep. Bean Improv. Coop*. 57:189–190.

Racancoj, A.J., A.G. Vargas, J.C. Rosas, C. Estevez de Jensen, J.S. Beaver and T.G. Porch. 2014. Response of Andean and Mesoamerican common bean genotypes to inoculation with *Rhizobium* strains. *Ann. Rep. Bean Improv. Coop*. 57: 245–246.

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

Steadman, J., and C.A. Urrea. 2017. Uganda trip report (Nov. 11-16, 2016). The Bean Bag. 35(1): 10 & 11.

Tamò, M. 2015. Biological control, a pillar of sustainable agriculture in Africa, at the International workshop "Visions for a Sustainable Agriculture," in Neuchatel, Switzerland, May 4–7, 2015.

Vandemark, G.J., M. A. Brick, J. D. Kelly, J.M. Osorno, and C.A. Urrea. 2017. Yield gains in dry beans in the U.S. *Ann. Rep. Bean Improv. Coop.* 60: 183-184.

Vargas, A., T.G. Porch and J.S. Beaver. 2014. Evaluation of the tepary bean (*Phaseous acutifolius*) CIAT germplasm collection for response to common bacterial blight and bean common mosaic necrosis virus. *Ann. Rep. Bean Improv. Coop.* 57:181–182.

Vásquez J., Estévez de Jensen C., Ghising, K., VanderWal, M., Kloberdanz M. and Osorno J.M., 2015. Screening field resistance to the root rot complex within the Andean Diversity Panel (ADP). Presentation at the Common Bean Disease Workshop on Angular Leaf Spot and Root Rot, Skukuza, South Africa, 20–23 July 2015.

II. Strategic Objective Two: Transforming Grain Legume Systems and Value Chains

Research output from LIL Projects SO2.1 and SO2.2

A.Refereed Journal Articles

Amanor-Boadu and K. Ross. 2017. On the Role of Food Hierarchies on Consumption Choices: The Case of Legumes. *In progress. Target journal: Food Policy.*

Amanor-Boadu, V., and R. Armah. 2017. A System Dynamics Approach to Legume Consumption and Production in Select Markets: 2020-2035. *In progress. Target journal: International Journal on Food System Dynamics.*

Bello Julia, Anne Namatsi Lutomia, Eric Abbott, Robert Mazur, Sostino Mocumbe, and Barry Pittendrigh. 2017. Making Agricultural Learning Accessible: Examining Gender in the Use of Animations via Mobile Phones (5:74-100) in M. Mills and D. Wake (eds.) *Empowering Learners with Mobile Open-Access Learning Initiatives.* Hershey PA: IGI Global. DOI: 10.4018/978-1-5225-2122-8.ch005.

Goettsch Lance H., Andrew W. Lenssen, Russell S. Yost, Ebby S. Luvaga, Onesmus Semalulu, Moses Tenywa, Richard Miiro and Robert E. Mazur. 2017. Improved production systems for common bean on Ferralsol soil in south-central Uganda *African Journal of Agricultural Research* 12(23):1959-1969. DOI: 10.5897/AJAR2017.12122.

Goettsch Lance H., Andrew W. Lenssen, Russell S. Yost, Ebby S. Luvaga, Onesmus Semalulu, Moses Tenywa, and Robert E. Mazur. 2016. Improved production systems for common bean on Phaeozem soil in south-central Uganda A*frican Journal of Agricultural Research* 11(46):4796-4809. DOI: 10.5897/AJAR2016.11760.

Mfikwa, Adelina, and Freddy Kilima. 2014. Factors Influencing the Consumption of Pulses in Rural and Urban Areas of Tanzania. *Tanzania Journal of Agricultural Sciences 13* (2).

Rocha António, Ricardo Maria, Unasse S. Waite, Uatema A. Cassimo, Kim Falinski and Russell Yost. 2017. Improving grain legume yields using local Evate rock phosphate in Gùrué District, Mozambique. *African Journal of Agricultural Research* 12(22):1889-1896. DOI: 10.5897/AJAR2017.12331.

B. Book Chapters

C. Other Publications

(reports, conference papers, working papers, manuals, etc.)

(Presentations and Abstracts for posters from the Feed the Future Legume Innovation Lab Grain Legume Research Conference 2017 are at http://legumelab.msu.edu/lil_burkina_faso_conference/bfagenda)

Chitete, M., H. Phiri, L. Mapemba, V. Amanor -Boadu, and J. Dzanja. 2017. Analysis of Structure, Conduct and Performance of Beans Marketing in Malawi: A Case Study of Lilongwe District. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

Kenamu, L. D. Mapemba, K. Ross and V. Amanor-Boadu. 2017. Household Common Beans Consumption Behaviour in Urban Malawi: Empirical Evidence from Lilongwe City. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

Mazur, R., N. Bwambale and V. Salegua. 2015. Land Rights and Integrated Soil Fertility

Management in Uganda and Mozambique. Paper presented at LANDac Conference 2015–Land Governance for Equitable and Sustainable Development. Utrecht, Netherlands, 8–10 July 2015.

Moyo, M., V. Amanor-Boadu, K. Ross, L. Mapemba and J. Dzanja. 2016. The Common Bean Subsector in Malawi: Current and Future Outlook of Yield, Area and Overall Production. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

Msukwa, W., J. Mangisoni and L. Mapemba. 2017. Household Demand for Common Beans in Lilongwe District of Malawi. Policy Brief, Lilongwe University of Agriculture and Natural Resources Lilongwe, Malawi.

Ross, K.L., A. Shanoyan, V. Amanor-Boadu, Y. A. Zereyesus, and G. Tembo. 2014. From subsistence to commercial production: factors affecting smallholder bean and cowpea producers market participation in Zambia. Paper presented at the Annual World Symposium of the International Food and Agribusiness Association, Cape Town, South Africa, June 16–17, 2014.

Ross, K.L., V. Amanor-Boadu, and L. Mapemba. 2015. Understanding consumer choice for grain legumes: recent evidence from Malawi. Paper prepared for presentation at the 90th Annual Conference, Honolulu, Hawaii, Western Economics Association International, June 28–July 2, 2015.

III. Strategic Objective Three: Enhancing Nutrition

Research output from LIL Project SO3.1 and Masfrijol

A. Refereed Journal Articles

Agapova, et al. 2018. Additional common bean in the diet of Malawian children does not affect linear growth, but reduces intestinal permeability. *J Nutr* (accepted)

Borresen, Erica C., Lei Zhang, Indi Trehan, Nora Jean Nealon, Kenneth M Maleta, Mark J Manary, Elizabeth P Ryan. 2017. The nutrient and metabolite profile of 3 complementary legume foods with potential to improve gut health in rural Malawian children. Curr Dev Nutr 1 (10): e001610.

Ngoma, et al. 2018. Effect of cowpea flour processing on the chemical properties and acceptability of a novel cowpea blended maize porridge. *PLoS ONE* (under review).

Stephenson, K.B., Agapova SE, Divala O, Kaimila Y, Maleta KM, Thakwalakwa C, Ordiz MI, Trehan I, Manary MJ. 2017. Complementary feeding with cowpea reduces growth faltering in rural Malawian infants: a randomized, blinded, controlled clinical trial. Am J Clin Nutr 106(6):1490-1499. DOI: 10.3945/ajcn.117.160986.

Trehan, Indi, Nicole S. Benzoni, Alfred Z. Wang, Lucy B. Bollinger, Theresa N. Ngoma, Ulemu K. Chimimba, Kevin B. Stephenson, Sophia E. Agapova, Kenneth M. Maleta and Mark J. Manary. 2015. Trials 16: 520. Common beans and cowpeas as complementary foods to reduce environmental enteric dysfunction and stunting in Malawian children: study protocol for two randomized controlled trials. DOI: 10.1186/s13063-015-1027-0

B. Book Chapters

C. Other Publications
(reports, conference papers, working papers, manuals, etc.)

Curran J, McLachlan M, Black R, Widders I, Manary M. 2017. Collaboration Among Sectors to Increase Pulse Consumption *Ann N Y Acad Sci.* 2017;1392(1):3-5. doi:*10.1111/nyas.13321*

IV. Strategic Objective Four: Improving Outcomes of Research and Capacity Building

Research output from LIL Project SO4.1

A.Refereed Journal Articles

Maredia, M. K., Reyes, B. A., Ba, M., C. Dabire, Pittendrigh, B., and Bello-Bravo, J. 2017. Effectiveness of animation videos in inducing technology adoption: A field experiment in Burkina Faso. *Information Technology for Development (April 19, 2017)*

Maredia, Mywish, Shankar, Bhavani, Kelley, Timothy, Stevenson, James. 2014. Impact assessment of agricultural research, institutional innovation, and technology adoption: introduction to the special section. *Food Policy* 44 214–217.

Reyes, Byron A., Maredia, Mywish, Bernsten, Richard H., Rosas, Juan Carlos. 2014. Have investments in bean breeding research generated economic benefits to farmers? The case of five Latin American countries. *Agricultural Economics* (Submitted).

B. Book Chapters

C. Other Publications (reports, conference papers, working papers, manuals, etc.)

DeYoung, David, Byron Reyes, Juan Osorno, Julio Cesar Villatoro and Mywish Maredia. 2017. An Overview of Bean Production Practices, Varietal Preferences, and Consumption Patterns in the *Milpa* System of the Guatemalan Highlands: Results of a Farm Household Survey. *Staff Paper 2017-08*. Michigan State University Department of Agricultural, Food and Resource Economics Staff Paper Series.

Magen, Benjamin, Crawford, Eric W., Maredia, Mywish. 2013. Economic impact of CRSP's investment in the development and dissemination of improved cowpea varietal technology: New evidence from Senegal. *Impact Assessment Research Brief 4*. Michigan State University: Dry Grain Pulses CRSP.

Magen, Benjamin, Crawford, Eric W., Maredia, Mywish. 2013. Impact Economique des investissements du CRSP sur le développement et la diffusion des variétés améliorées de niébé: Nouvelle évidence du Sénégal. Impact Assessment Research Brief 4. Michigan State University: Dry Grain Pulses CRSP (French translation).

Maredia, M, Shupp, R., Opoku, E., Mishili, F., Reyes, B., Kusolwa, P., Kusi, F., and Kudra, A. 2017. Do farmers economically value seeds of different quality differently? Evidence from willingness to pay studies in Tanzania and Ghana. MSU International Development Working Paper. East Lansing: Michigan State University *(forthcoming)*

Maredia, M., Reyes, B. A., D. DeYoung. 2014. Farmer perspective on the use of and demand for seeds of improved bean varieties: Results of beneficiary surveys in Guatemala, Honduras and Nicaragua. Staff Paper 2014–04. Department of Agricultural, Food and Resource Economics, Michigan State University, East Lansing.

Reyes, B. A., D. DeYoung and M. Maredia. 2014. Effectiveness of the bean seed dissemination models implemented under the Bean Technology Dissemination (BTD) Project: Results of key informant interviews in Guatemala, Honduras and Nicaragua. Staff Paper 2014–03. Department of Agriculture, Food and Resource Economics, Michigan State University, East Lansing.

Reyes, Byron A., Maredia, Mywish, Ba, Malick, Clementine, Dabire, Pittendrigh, Barry. 2013. Economic impacts of biocontrol research to manage field insect pests of cowpea in Burkina Faso: Baseline survey report. Department of Agricultural, Food and Resource Economics Staff Paper 13-04. East Lansing, Michigan: December 2013.

Reyes, Byron A., Mywish K. Maredia, Richard H. Bernsten, and Juan Carlos Rosas. 2016. Opportunities Seized, Opportunities Missed: Differences in the Economic Impact of Bean Research in Five Latin American Countries. MSU International Development Working Paper 151. East Lansing: Michigan State University. *(November 2016)*

Sauer, C., Mason, N. M., Maredia, M. K., and Mofya-Mukuka, R. 2016. Impacts of legume technologies on food security: Evidence from Zambia. *FSP Research Paper No. 36*. East Lansing, MI: Feed the Future Innovation Lab for Food Security Policy. *(December 2016)*

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