DRY GRAIN PULSES

Collaborative Research Support Program (CRSP)

Five-Year Program Technical Report 2007–2012

USAID FROM THE AMERICAN PEOPLE

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In Memory of . . .

Ben Hassankhani

Administrative Officer for the Bean/Cowpea and Dry Grain Pulses CRSPs (2002–2013)

See tribute on page 115.

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Preface

DRY GRAIN PULSES COLLABORATIVE RESEARCH SUPPORT PROGRAM (PULSE CRSP)

The continued persistence of hunger, malnutrition, and poverty in the twenty-first century developing world called—and continues to call—research scientists to develop strategies toward achieving sustainable reductions in these areas. A strategy that linked these interrelated and mutually reinforcing social dynamics with pro-growth support for smallholder farmers and institutional capacity building within affected countries proved the most promising approach to achieving long-term and regional improvement.

Because pulses are grown and consumed throughout the world, particularly in regions with high incidents of poverty and hunger, and because of their exceptional nutritional value in meeting protein and mineral needs, they seemed the ideal commodity for addressing the multidimensional nature of poverty—hunger, malnutrition, poor household and national economies, and agricultural challenges. An umbrella program that would manage numerous independent but mutually beneficial projects focused on this aspect of the food economy seemed most likely to succeed in both short- and long-term improvements in household food and financial security. Embodied in the Dry Grain Pulses Collaborative Research Support Program (Pulse CRSP), this program was funded from October 1, 2007, to September 30, 2012.

In addition to the need for developing countries to address their peoples' food and nutritional insecurity in the midst of poor soil, insect pests, plant diseases, climate change, and other food growing difficulties that led to unacceptably low levels of productivity, the globalization of markets and fundamental changes in food value chains in the twenty-first century offered new opportunities for smallholder farmers in the global pulse industry to access these opening markets. The Pulse CRSP set out to address both these individual and community-wide challenges and opportunities through its focus on results-driven scientific agricultural research.

The global mission of the Dry Grain Pulses Collaborative Research Support Program (Pulse CRSP) was to link the interrelated and mutually reinforcing dynamics of hunger, malnutrition, and poverty with pro-poor growth, private sector investment, and institutional capacity building to support future country-led efforts for development through a five-year research and capacity building program to contribute to the following:

- Economic growth and food and nutritional security through knowledge and technology generation
- Sustainable growth and competitiveness of pulse value chains utilizing socially and environmentally compatible approaches
- Empowerment and strengthened capacity of agriculture research institutions in USAID priority countries
- USAID's Feed the Future and Global Food Security Research Strategy
- Achievement of Title XII legislative goals for CRSPs, including the generation of dual benefits to developing country and U.S. agriculture.

This program built upon the scientific advances and technological achievements of the Bean/Cowpea CRSP while responding to the agriculture development priorities and objectives set forth in USAID's Feed the Future (FTF) Global Food Security Research Strategy and in the Development Strategies by USAID Missions in FTF Focus countries and regions. These strategies seek to address the root causes of hunger and forge long-term solutions to these challenges. The strength of the Pulse CRSP is that it mobilized the cutting-edge research capacities of U.S. universities in such strategic areas as genomics, marker-assisted selection, root biology, symbiotic plant-Rhizobia interactions, systems science, sustainable community livelihoods, gender, communication science, value-chain research, and market development to achieve its goals.

The Pulse CRSP worked to address the causes of food insecurity through science-based research that addresses the challenges of smallholder farmers. Pulse breeding for high yield potential and resistances to abiotic and biotic stress factors, integrated insect pest management, improved storage methods and technologies, and enhancing soil fertility and/or improving a plant's ability to utilize soil nutrients are among the Pulse CRSP projects.

This final report of the Pulse CRSP presents individual reports by each of the Phase II (eight) and Phase III (four) projects, including the Phase I project that was completed in 2010. Through these projects, the Pulse CRSP achieved its technical vision through a portfolio of integrated, multidisciplinary, collaborative research, outreach, extension, institutional capacity building, and impact assessment activities on beans, cowpeas, and related pulses in accord with its Global Themes:

1. To reduce pulse production costs and risks for enhanced profitability and competitiveness
2. To increase the utilization of pulse food products and ingredients to expand market opportunities and to improve community health and nutrition
3. To improve the performance and sustainability of pulse value chains, especially for the benefit of women
4. To increase the capacity, effectiveness, and sustainability of agriculture research institutions that serve pulse sectors and developing country agricultural industries.

The twelve projects presented in this final report involved collaborative research, long- and short-term training, and technology dissemination activities in 13 sub-Saharan African countries (Benin, Burkina Faso, Mali, Niger, Senegal, Kenya, Rwanda, Uganda, Tanzania, Mozambique, South Africa, Zambia, and Angola) and three Latin American countries (Haiti, Honduras, and Ecuador). Of this group, ten were USAID Feed the Future focus countries. More than 25 host country institutions, including National Agriculture Research Institutions, agriculture universities, and NGOs collaborated with the lead U.S. universities in these projects.

In contrast to the annual *Highlights* reports, this final report of the Dry Grain Pulses Collaborative Research Support Program focuses on outputs and outcomes realized from the research and training activities over the five-year grant period from 2007–2012. The expectation is that these outputs in knowledge and technology will be adopted and effectively utilized by stakeholders in pulse value chains (e.g., smallholder farmers, traders, community organizations, and consumers) in the future.

Some of the outputs represent achievements that will provide expanded opportunities for agricultural scientists (some in the Feed the Future Legume Innovation Lab) to continue to develop solutions to major constraints to pulse cropping and value chains. The ongoing development of agricultural solutions and economic opportunities ensures that the total impact and benefits of the Pulse CRSP will continue to be realized for years into the future—some through the Legume Innovation Lab and some through other means.

Readers, stakeholders, and contributors to this final report are encouraged to review its contents thoroughly, and to utilize the knowledge and technology it reports that may benefit their own research or institutions. A comprehensive view of the scope of vital outputs generated by each project and the new knowledge, management practices, and technologies resulting from the research activities provide an excellent picture of how the Pulse CRSP uses collaborative science research to advance economic growth as well as food and nutrition security in developing countries. It is these outputs that will benefit stakeholders of pulse value chains—from producers in Africa and Latin America to the United States. More detailed information, for those interested in the particulars of particular achievements, may be obtained through the comprehensive annual reports, consulting with PIs for particular projects, and/or the Management Office, by request. These reports will be available online in an archived section of the Legume Innovation Lab's website at www.legumelab.msu.edu and through the Management Office.

As the director of the Dry Grain Pulses CRSP, I want to thank all the participating U.S. and host country scientists and institutions that have partnered with this program. You have provided evidence through your respective reports of your commitment to a global vision of ensuring food and nutritional security throughout the world and increasing economic stability in underserved regions through improved pulse value chains. Your adherence to the highest scientific, ethical, and professional standards in the conduct of this collaborative research, in providing relevant and sound academic experiences for degreed trainees and host country farmers, and to making professional contributions that have improved pulse crops and will continue to improve the pulse industry have demonstrated the success of this program.

I also wish to thank the Office of Agricultural Research and Policy, Bureau of Food Security, USAID–Washington, for its financial support for this worthy program. USAID's investment in the Dry Grain Pulses CRSP reflects its recognition of the vital importance of pulse crops in contributing to the nutritional and food security of the rural and urban poor as well as to providing opportunities for resource-poor farmers and other value chain stakeholders to generate income and rise above poverty. The host country and U.S. scientists and institutions partnering in this endeavor are also to be thanked and commended for their commitment to scientific excellence, to generating new knowledge and technologies that bring the hope of a better tomorrow, and to training a new generation of scientists and professionals who will provide leadership to the agricultural development of many African and Latin American countries.

Dr. Irvin E. Widders

Irvin E. Widders

Director
Dry Grain Pulses CRSP
Michigan State University

Using Improved Pulse Crop Productivity to Reinvigorate Smallholder Mixed Farming Systems in Western Kenya

PI-CU-1

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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

Two Short Rains (SR)–Long Rains (LR) cropping cycles were completed in the South Nandi region of Western Kenya focusing on crop vigor enhancing strategies that improve production of staple crops, maize, and bean, while also introducing a new multipurpose grain legume, *Lablab purpureus*, with good potential for improving household food security and addressing soil degradation. Major project activities included participatory evaluation of vigor enhancing strategies by 70 collaborating farmers across a soil fertility gradient; training and on-farm testing of the strategies by 175 farmers associated with NGO/CBO groups in Busia, Teso, Butula, and Vihiga districts; facilitating exchange visits to promote farmer learning and knowledge sharing; implementation of researcher-managed replicated experiments at four sites across the gradient; and technical/financial support for six students (three women, three men) pursuing master's degrees at Kenyan universities.

During the Long Rains season, farmers made substantial gains in maize productivity by utilizing alternative fertilization strategies, particularly incorporated lablab residues or half compost and half DAP.

Short Rains results were consistent over both years. Farmers realized a 15 percent yield increase by substituting improved bean variety KK8 for their own. By substituting KK8 and adding TSP fertilizer, farmers achieved a 41–71 percent yield gain. Phosphorus fertilizer increased lablab grain and biomass productivity, although the effect was not as pronounced as with beans.

During the Long Rains season, farmers made substantial gains in maize productivity by utilizing alternative fertilization strategies, particularly incorporated lablab residues or half compost and half DAP. Maize yield gains relative to farmer practices were greatest at the low soil fertility site (25–59 percent) and smallest at the high soil fertility site (-2–10 percent).

During exchange visits, farmers reported using some or all of the vigor enhancing strategies on other parts of their farms. Within the Kapkerer–Koibem exchange group, 32 percent of the participants had up-scaled boma compost, 40 percent were using KK8 beans instead of local varieties, 75 percent were growing lablab, and eight percent were following improved spacing/seed rate strategies. Boma compost was being used by 42 percent of farmers from the Kiptaruswo–Bonjoge exchange group; KK8 bean and lablab were being grown by 38 percent and 80 percent of the farmers, respectively.

Five master's students completed their degrees or are finalizing their theses.

PROBLEM STATEMENT AND RESEARCH APPROACH

Many rural households in the East African highlands are no longer self-sufficient in beans, a critical source of food and income. Farmers' inability to afford fertilizer inputs coupled with continuous cropping on ever shrinking land holdings has led to degraded and infertile soils and a concomitant decline in crop vigor, pest and disease tolerance, and overall system productivity.

Low bean and maize productivity in Western Kenya is related to both soil fertility and biological constraints. Legumes can be important options for rebuilding soil fertility, but poor utilization of applied P fertilizers, conflicts between soil renewal and immediate food and income needs, and low fixed nitrogen returns from many grain legumes have limited expected returns. Additional production constraints and risks are diseases and pests: angular leaf spot, anthracnose, root rots, bean stem maggot, nematodes, and root-feeding insects.

We hypothesize that vigorous establishment of pulse crops leads to increased pest/disease resistance and improved N fixation and nutrient accumulation, which ultimately reduces risk, benefits system productivity, food security, and human nutrition. Practices promoting early plant vigor and growth encourage bigger and deeper root systems, which can compete more effectively with soil borne pathogens.

Consumption of pulses is essential for addressing iron deficiency, anemia, and stunting caused by inadequate intakes of zinc. Knowledge about the mineral nutrient content of staple food products is needed to inform selection of appropriate cultivars to benefit consumers' health and to assist policy makers in meeting national health outcomes.

ACHIEVEMENTS AND OUTPUTS

KARI field staff conducted numerous meetings in the South Nandi project area to educate farmers on the use of vigor enhancing strategies (seed priming, root rot tolerant bean germplasm, boma compost, Triple Super Phosphate [TSP] and Minjingu Rock Phosphate [MRP] fertilizers; and combining inorganic and organic fertilizers and multipurpose lablab); to facilitate farmer testing of these strategies; and to promote farmer learning through exchange visits and knowledge sharing with scientists, university faculty, and students. KARI scientists also attended and led similar programs with REFSO, ARDAP, and AVENE.

The project continued support for on-farm verification trials across the established soil fertility gradient sites of Kapkerer (low soil fertility), Kiptaruswo (low-medium soil fertility), Bonjoge (medium high soil fertility), and Koibem (high soil fertility). Seventy farmers participated in lablab and common bean verification trials.

Farmers selected root rot tolerant KK8 bean and/or lablab treatments according to their interests and available resources. The three treatments that were tested by the largest numbers of farmers were TSP (55 farmers), priming (44 farmers), and TSP and priming (43 farmers); 58 farmers conducted a final round of verification trials on alternative fertilization strategies for their main maize–bean intercrop.

Farmers tested a more targeted and concentrated application of DAP, compost applied in the planting furrows, a lablab residue treatment, and a half lablab–DAP treatment—and compared these treatments to their own fertilizers.

Collaborations with NGO and farmer groups on Vigorous Growth of Pulses

The project supported two NGOs (ARDAP and REFSO) and one CBO (AVENE) working with farmers to scale-up and disseminate vigor enhancement strategies and to monitor farmers' reactions and crop responses to these strategies in the Busia, Teso, Butula, and Vihiga districts of Western Province. ARDAP conducted farmer verification trials and seed bulking activities; REFSO concentrated on bulking bean and lablab seed for farmer testing; AVENE activities mainly consisted of farmer verification trials.

ARDAP
Twenty farmers compared the performance of different vigor enhancement strategies with their own production practices. All the tested crop vigor enhancement options substantially outperformed farmer practices.

AVENE
Sixty-five farmers in the Vihiga district tested a variety of crop vigor enhancement options on bean, lablab, or both. These tests were compared to farmer practice in demonstration plots. Plots planted with KK8 bean plus compost or DAP outperformed farmer practice on most of the farms that were involved in the trials.

AVENE also works with two women's groups to promote small-scale entrepreneurship through table banking, small-scale farming, and adult education. These groups were trained on high quality compost making and management, and provided with lablab and KK8 bean seeds for bulking.

Short Rains Performance Results

Beans

Farmers were most interested in comparing how unfertilized KK8 performed relative to their own unfertilized varieties and how KK8 performed with or without TSP fertilizer.

Mean yields by treatment were 635 kg/ha for unfertilized farmer varieties; 728 kg/ha for unfertilized KK8; and 958 kg/ha for KK8 fertilized with TSP. Farmers realized a 0 to 31 percent yield increase across the fertility gradient by substituting improved germplasm for their own variety. By substituting KK8 and adding TSP fertilizer, farmers achieved a 41 to 71 percent yield increment. Some of the factors that contributed to these yield effects include a germplasm contribution, with KK8 plants having consistently more pods at harvest, giving them higher yield potential than the varieties farmers are currently growing; TSP's contribution, in which applying TSP fertilizer increased the numbers of pods per plant even further relative to unfertilized KK8; TSP application also enhanced the survival of plants to harvest; and Lablab, whose grain yields followed the fertility gradient.

Generally, treatment effects were inconsistent across sites for most of the variables evaluated (emergence, stand counts, pest infestation incidence, and yield). However, several potential trends were detected: 1. P fertilization and/or priming enhanced plant survival at the two lower fertility sites and 2. TSP application increased lablab productivity.

Long Rains Performance Results

Across the communities, the most popular alternative Long Rains fertilization strategies evaluated were the concentrated application of DAP, incorporated lablab residues, and the half lablab–half DAP mixture. At individual communities, plant composts were popular at Kapkerer and composted manure at Koibem.

Across communities, mean maize yields in the alternative fertilization treatments were consistently higher than mean farmer practice maize yields.

Overall, bean stand establishment was better at Bonjoge (66 percent of target stand) and Koibem (63 percent) than at Kapkerer (57 percent) and Kiptaruswo (59 percent). Also notable was that the two full organic treatments (compost; lablab) had a higher percent stand establishment, 67 percent, compared to 58 percent for the other fertilization strategies, which suggests that the residues may help retain moister conditions more suitable for seed germination.

Overall, bean performance varied substantially by treatment; bean productivity was poorest in farmer practice, lablab, and compost and best in the half DAP and full DAP treatments. Maize yield gains relative to farmer practices were greatest at the lowest fertility site and smallest at the highest.

Across communities, mean maize yields in the alternative fertilization treatments were consistently higher than mean farmer practice maize yields, despite maize stands in these treatments being 30 percent lower than the target stand.

Farmer-to-Farmer Exchange Visits

Efforts were made to create awareness with the Koibem farmers (high soil fertility group) about the effects of soil fertility degradation. As a result Kapkerer farmers (low soil fertility) exchanged with Koibem farmers; and Kiptaruswo farmers (medium-low soil fertility) swapped with Bonjoge farmers (medium-high soil fertility).

At each site, groups toured four farmer verification trials and the researcher managed a replicated experiment under maize cultivation. Host farmers explained the alternative fertilization options being tested in their verification experiments. Question and discussion periods after each presentation provided a forum for farmers to discuss benefits and constraints. Across all sites, farmers reported using some or all of the vigor enhancing strategies on other parts of their farms. All the exchange visit participants preferred lablab first for soil fertility.

Simple, pictorial training materials were prepared for distribution on how to grow lablab and its multipurpose benefits; use of boma compost, organic/inorganic fertilizer mixtures, and lablab residues as alternative fertilization strategies for intercropped maize and beans; and P fertilizer use to improve productivity of grain legumes.

In the South Nandi project area, 130 households were surveyed to determine which of the vigor enhancing strategies they preferred and which they planned to scale up. They were also questioned about the extent of labor involved with the lablab residue incorporation. Participants indicated that half compost and half DAP and incorporated lablab residues (lablab only) were most preferred; however, preference responses differed across the soil fertility gradient, with lablab least preferred at the high soil fertility site but most highly ranked at the lower soil fertility sites. Most respondents indicated that the amount of labor needed for incorporating lablab residues was greater but felt the outcomes were worth the extra effort.

Factors Affecting Pulse Productivity across a Soil Degradation Gradient

Data from 2009–10 Short and Long Rains crops have been collected, compiled, and shared among all collaborators. Datasets include plant emergence and mortality, nodule counts, and grain and biomass yields of lablab, beans, and maize.

- At Bonjoge and Koibem, average lablab yields were greater than 1,000 kg/ha and either outperformed or gave comparable grain yields as bean. The Bonjoge and Koibem results were similar to the farmer verification plots in the same clusters, but at Kapkerer and Kiptaruswo halo blight reduced the replicated experiment lablab grain yields to very low levels compared to the farmer plots in the same communities. Likewise, bean yields from the replicated plots at all sites except Koibem were 50 percent less than those obtained on the farmer trials. Koibem bean yields were good and comparable to the farmer plot yields.

- The Short Rains treatments had little or no impact on pest and disease incidence or survival of lablab plants. The TSP treatment had significantly reduced aphid incidence across all sites and reduced halo blight at Kapkerer but had no effect on plant stand or root rot. Seed priming significantly reduced plant stands by five percent across all sites.
- The TSP treatment did not have significant impact on bean plant populations, root rot, aphid incidence or beanfly pupae/larvae; however, results indicated slight reduction trends in root rot and beanfly pupae/larvae with TSP. The seed priming treatment did not translate into an effect on either lablab biomass or grain yields, despite the negative effects of seed priming on lablab plant stand.

Maize–Bean Intercrop

At all sites, bean yields were substantially higher than 2009 yields; maize yields in 2010 were similar to 2009. The lablab residue treatments alone produced a 22 percent average increase in bean yield, but the effect was dominated by Kapkerer and Bonjoge, so the lablab residue treatment effect was not statistically significant across all sites.

Both the fertilizer and bean variety treatments had large and significant impacts on bean yield at all sites. The half compost–half DAP fertilizer treatment increased bean yields on average 37 percent compared to the no fertilizer treatment. Yields from the root rot tolerant bean variety KK8 were on average 84 percent higher than the root rot susceptible bean variety GLP2.

Due to timely planting and low pest and disease incidence, bean plant populations at two weeks were high, averaging 91 percent of seeds sown across all sites—and stands remained relatively stable up to flowering; however, by harvest a substantial amount of plant mortality reduced average populations to 63 percent. We can infer from the high plant populations that the incidence of root rot, chafer grubs, common bean blight, and bean common mosaic virus must have been low early in the season, but that the severity of these diseases plus late season maize lodging combined to substantially reduce plant stands later in the season. Only the bean variety treatment had a significant impact on plant populations. Over the course of the season, plant populations with KK8 were higher than GLP2 by eight percent.

Lablab residue treatments did not appear to exacerbate root rot severity. Lablab residue treatments had the biggest impact on maize grain, and stover yields, increasing them from 52 percent (lablab removed) to 78 percent (lablab incorporated), while stover yields were increased 34 percent (lablab removed) and 46 percent (lablab incorporated).

The impact of chafer grubs on seasonal bean mortality or bean yields in 2010 was inconsistent. While the replicated experiment data to date have not demonstrated a negative impact of chafer grubs in association with incorporated lablab residues, lower bean yields in the farmer verification trials with incorporated lablab residues does suggest that chafer grubs may be a contributing factor.

Germplasm testing

A master's student compared the agronomic responses of cowpea lines ICV6, ICV12, CB46, IT90K-284-2, IT83D-442 from U. California, Riverside, and local check Khaki at each of the four project sites across the soil fertility gradient to identify varieties with the most potential for cowpea grain production in the wet, cool, and higher elevation environments of Western Kenya, identifying some promising cowpea varieties for future grain production research at higher elevation sites. Yields from the introduced bean varieties ranged from 133 g/plot to 1,000 g/plot and the local check yields averaged 467 g/plot and 458 g/plot. Seven of the lines tested were selected for utilization in future breeding efforts by the KARI Grain Legume program.

Resistance to BCMV and BCMNV

Master's research was initiated during the Long Rains 2010 season with four screening trials distributed across the project soil fertility gradient sites to characterize commercial and advanced breeding bean germplasm for its reaction to BCMV and BCNMV and to verify the prevalence of BCMV and BCMNV in Western Kenya.

A total of 32 breeding lines from the KARI–Kakamega breeding program were tested at each site. Stand counts, number of plants with BCMV and BCMNV symptoms, and severity of BCMV and BCMNV symptom scores were collected along with grain yields at maturity. Preliminary results indicate that both BCMV and BCMNV were prevalent across all sites within the South Nandi project area; however, sufficient genetic variation for manipulation to develop bean varieties with multiple disease tolerance to BCMV and BCNMV was observed.

Nutrient Analysis of Grain and Edible Leaf Samples

This activity documented the nutrient content of bean and lablab food products generated from local varieties and under farm environmental conditions to obtain accurate assessments of potential food nutrient intakes by smallholder farm households in Western Kenya. Bean and lablab grain as well as lablab leaf samples were collected across the soil fertility gradient and analyzed.

Bean grain nutrient contents at Kapkerer, Kiptaruswo, and Koibem were not significantly different from one another, but Bonjoge samples had consistently lower bean nutrients (except N, Ca, Fe, Cu), possibly due to particularly high pest and disease severity at the site that season. Surprisingly there were no differences in nutrient content between the farmers' local bean varieties or KK8, which suggests similarity in genetic potential between these bean varieties in nutrient content. No significant effects of TSP treatment on bean grain nutrient contents were noted. Lablab grain nutrient contents were statistically similar across the sites. No impact from TSP treatments on lablab grain nutrient contents was noted. Significant site differences were found in lablab leaf P, S, Ca, Mn, B, Fe, Cu, and Zn content results, but there were no consistent patterns to help in explaining why these differences arose. There were no effects of the TSP treatments on the nutrient content results for lablab leaf.

Results indicate that with the exception of Ca, lablab grain is generally more nutrient dense than bean with eight to 23 percent more of macronutrients N, P, and S and higher micronutrients of Mn, Fe, Cu, and Zn. Calcium, however, was 81 percent less in lablab grain than in bean grain. Crude protein levels derived from the total N contents were 18 percent in bean grain, 23 percent in lablab grain, and 26 percent in lablab leaf.

CONTRIBUTIONS TO INSTITUTIONAL CAPACITY BUILDING

All students but one who entered the program completed their master's degrees. Host country funds were obtained to support field research for two new master's students.

POTENTIAL DEVELOPMENTAL OUTCOMES AND BENEFITS TO PULSE VALUE CHAIN(S)

- Collaborations with local NGO/CBO groups more than doubled short-term training goals, with 175 households benefiting.
- All of the eight project vigor-enhancing strategies continue to be field tested by farmers.
- Five cowpea varieties obtained from the University of California, Riverside, and 10 nutrient-efficient bean lines from Zamorano–Pennsylvania State are being studied for grain production (cowpea), response to BCMV/BCNMV (bean), or performance under low soil P conditions (bean).
- All four HC partner organizations (KARI, University of Nairobi, Moi University, and Egerton University) continue to benefit from the project.
- Farmers have started to scale up within their farms: approximately 32–42 percent have up scaled boma compost; 38–40 percent were using KK8 beans instead of local varieties; 75–80 percent were growing lablab; and eight percent were following improved spacing/seed rate strategies.
- Two public–private partnerships were achieved through linkages with the Leldet Seed Company and Syngenta East Africa Ltd.

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

PII-ISU-1

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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

Project activities generated important achievements: 1. Bean quality and yield were improved through on-farm research on bean variety and fertilizer interactions and 2. Capacity building training was conducted with the six research groups covering germination testing; plant spacing; manure application; pest and disease management; harvesting, threshing, drying, and moisture testing; solarization and triple bagging; and sorting and seed selection. This training led to community-based production of quality seed, income from seed sales, and increased marketing. Print and video extension materials were developed and translated into local languages for training. Improved bean variety seeds were provided to 1,000 farmers (700 women) in 60 demonstration sites. Two farmer field days widely disseminated information about improved practices.

Bean quality and yield were improved through on-farm research on bean variety and fertilizer interactions.

To enhance nutritional value, appeal, and consumption of beans, research determined the influence of preprocessing methods on starch and protein digestibility, micronutrient bioavailability, and the sensory acceptability of bean flours. We developed appealing, nutrient-enhanced, and shelf-stable products now sold in Kampala. We facilitated farmers' learning about bean preparation for home meals and local products. Special field days were organized to train health workers and farmers to use bean flour in food preparation and to showcase local recipes. Rural microenterprises were created, selling snacks to children and for special occasions. Porridge for supplementary feeding was developed. The culinary and sensory characteristics of seven local and 18 improved bean varieties in Uganda and 16 improved varieties in Rwanda were analyzed.

Project households have increased their area planted in beans, market participation, and income. The collective marketing capabilities of farmer groups were strengthened through improved postharvest grain handling, better coordination of community grain bulking and storage, enhanced understanding of market price variations, and price and contract negotiation skills. The project team helped farmer groups develop business plans, improve record keeping and analysis, promote gender equity, and improve group dynamics. A multistakeholder bean value chain forum has been formed to identify key constraints and solutions for broad-based, successful market participation and to establish relationships throughout the value chain, from farmer to industry.

PROBLEM STATEMENT AND RESEARCH APPROACH

Agriculture in East Africa is characterized by women and men working in small-scale, rain-fed fields of poor soil fertility, averaging two hectares per household. Erratic bimodal rainfall patterns in recent years have further challenged cropping results. Farmers have had limited access to training for improved agronomic practices, quality seed, technologies to improve yields and reduce postharvest losses, and credit. Losses have been typically very high throughout the bean value chain due to poor harvest and postharvest practices and poor on-farm storage facilities. Beans on the market are typically poor quality and infested. Producers are not well linked to profitable markets, especially emerging sectors of domestic and regional markets. Traders operate on a small scale with limited investment capability. Availability and use of processed products remains very modest. Hunger and poverty are widespread.

Beans provide a strategic opportunity to help meet the Millennium Development Goal targets of reducing hunger and poverty in sub-Saharan Africa.

Beans provide a strategic opportunity to help meet the Millennium Development Goal targets of reducing hunger and poverty in sub-Saharan Africa through increased food security. Their short growth cycle and two growing seasons can play an essential role in sustainable livelihoods for small-scale farmers.

The lack of value-added bean products with reduced cooking time makes bean preparation laborious, with high fuel requirements; consumers also tire of monotonous flavors, reducing their bean consumption. Optimized processing (hulling, soaking, milling, fermentation, germination, and extrusion cooking) can enhance digestibility and nutritional value by reducing phytates and polyphenols that limit iron uptake and creating value-added, bean-based products.

Our efforts to market greater quantities of beans and new agroprocessed bean products through new agronomic practices and technologies within the Ugandan, Rwandan, and regional markets has shown encouraging progress. Collaboration since 2004 has increased food security and market readiness from nine to 77 percent among 800-plus farm households.

ACHIEVEMENTS AND OUTPUTS

To Improve Harvested Bean Yields and Quality

Evaluation and Promotion of Better Production and Management Practices

We trained six farmer groups in using established seed quality standards, establishing production and sales costs, and determining when to sell their seeds profitably.

Because overall bean productivity remains well below genetic potential, varying amounts of inorganic phosphorous were incorporated into low nutrient soils prior to planting to identify the level required to generate a profitable return on seed and N-fertilizer investment. The test examined whether an increased supply of phosphorus would lead to better agronomic performance on the genotypes Kanyebwa (a local variety) and NABE4 (an improved variety). Data show:

- Improved varieties had higher averages and more stable yields.
- The application of manure and phosphorous together with other good agronomic practices consistently led to moderately higher yields.
- Overall, phosphorus application did not have a significant effect on plant population.

Support Community-Based Seed Production (CBSP)

Significant improvements in seed management are necessary to effect a successful transition from household-based bean production to market-oriented production. To establish systems for community-based production of quality seed for local farmers to access, we trained six farmer groups in using established seed quality standards, establishing production and sales costs, and determining when to sell their seeds profitably. The training guide for CBSP is complete, with modules on agronomy, farm record keeping, and institutional development. Farmers were taught site selection, field layout, and how to select quality seed for planting—and to retain quality seed for subsequent planting and sale to other farmers, institutions, traders, and at the market.

Reducing Postharvest Losses through Solarization and Hermetic Storage (Triple Bagging)

At Makerere University, researchers evaluated the impact of solarization and triple bagging on beans in bulk storage under Ugandan conditions. Of particular interest was reducing postharvest losses due to bruchid infestation and maintaining seed viability and the culinary properties of beans.

Triple bagged bean and maize samples retained more than 80 percent germinability and grain quality after three months and 75 percent after four months.

Triple bagging involves storing grains in an air tight environment using two inner HDPE plastic bags and a strong outer woven polypropylene bag. Solarization involves killing insects and larvae through exposure to high temperatures. In this study, beans and maize were triple bagged and stored for seven months. Moisture content, broken grains, foreign material, insect damage, number of live/dead insects, and germinability were determined periodically. Triple bagged samples retained more than 80 percent germinability and grain quality after three months and 75 percent after four months. Triple bagging was even more effective for maize, maintaining grain quality and germinability above 90 percent even after seven months.

Solarization of beans and maize, inoculated with live insects, was achieved by placing a one cm layer of grain on black polythene, covered by transparent polythene, under the sun, with the effects evaluated hourly by counting the dead and live insects over six hours. Solarization led to death of inoculated insects after six hours, though more so in beans than in maize.

Evaluate Adoption of Improved Integrated Crop Management Practices and Technologies

Nearly 1,000 farmers have participated in on-farm training sessions for integrated crop management practices and technologies. Print and video extension materials on smallholder farm production of common beans in Uganda have been finalized and translated into Luganda, including improved site selection, incorporation of compost and manure in soils, optimizing plant and row spacing, scheduling of weeding, integrated pest management, grain harvest/threshing, postharvest drying on tarpaulins, grain moisture monitoring and grading, and hermetically sealed, triple-bag storage.

In mid-2012, a sample survey was conducted of 132 farm households that varied in number of growing seasons since their training. The results concerning awareness and implementation of production, postharvest, processing, and marketing practices are presented in table 1.

CROP MANAGEMENT PRACTICES	Awareness Level	Implementation Level		
	Taught Others or Received Training	Already Do	Definitely Will	Interested
PRODUCTION				
Manure Application	87.8	34.1	4.5	47.7
Germination Test	84.9	41.2	2.3	48.1
Field Preparation	93.2	62.9	1.5	33.3
Line Planting	96.2	61.4	0.8	35.6
Timely Weeding	95.5	63.6	0.8	34.8
Pest Management	87.3	42.4	2.3	42.4
Disease Management	76.5	40.9	2.3	43.9
POSTHARVEST				
Timely Harvesting	91.7	61.4	1.5	35.6
Drying on Tarpaulin	87.1	50.8	3.0	38.6
Gently Threshing	84.0	59.1	0.8	31.1
Solarization	80.3	48.5	3.0	38.6
Cleaning	91.0	56.8	0.8	39.4
Airtight Storage	83.4	50.8	0.8	42.4
PROCESSING				
Soaking and Malting	65.2	31.8	6.1	42.4
Flour Making	68.9	30.3	6.1	43.2
Make Snacks/Cakes for Sale	68.1	29.5	4.5	46.2
COLLECTIVE MARKETING				
Participate in Group Sales	79.6	40.2	8.3	40.2
Active Leadership Role	71.8	34.6	7.7	44.6
Packaging and Labeling	67.2	33.6	6.9	43.5

Table 1. Awareness and Implementation of Production Postharvest, Processing, and Marketing Practices

Strengthen Learning and Sharing of Innovative Practices

Approximately 150 farmers (100 women) and other stakeholders participated in the Pulse CRSP field day in Butansi in 2010 to share the knowledge they had acquired through research, demonstrate and explain new management practices and technologies (germination testing, site selection, land preparation, row planting and spacing, timely weeding, pest management, harvesting methods, postharvest handling, moisture content, seed preservation), storage technologies (triple bagging, airtight plastic containers), and community-based seed production. Two additional field exposure visits were conducted in 2011.

In 2012, three meetings to share research and development results and to strengthen the learning network were held: the first, a value chain stakeholder forum with farmers, input dealers, traders, credit providers, institutional consumers, NGOs, local government, research and academia, processors, nutritionists, and sales outlets to characterize and develop the bean value chain in the context of Kamuli; the second involving project dissemination in Kampala with key stakeholders; the third on management practices and technologies for integrated crop management.

Dissemination workshop

Scaling up dissemination and adoption of recommended practices and technologies has already begun in Uganda. Specific practices include establishing direct links between project communities and NaCRRI to obtain high quality seed and varieties for farmer-based experimentation; use of training materials developed through the Pulse CRSP project; community-based seed production systems; and hermetic storage of grain and seed.

To Enhance Nutritional Value and Appeal of Beans through Appropriate Handling and Processing

During Phase I, our preprocessing methods developed bean flour with significantly reduced cooking times (15 minutes), followed by recipes utilizing the fast cooking bean flour. In Phase II, we sought to promote increased bean consumption by communicating benefits and preferences to national bean programs and the private sector. We then engaged the private sector in value addition and commercialization of bean products to open up new markets for bean producers. Finally, to enhance children's daily nutrient intake of beans and bean products, we developed products acceptable to students and practical in schools, hospitals, and humanitarian agencies.

Modeling Iron Bioavailability in Beans and Establishing Effect of Extrusion Cooking

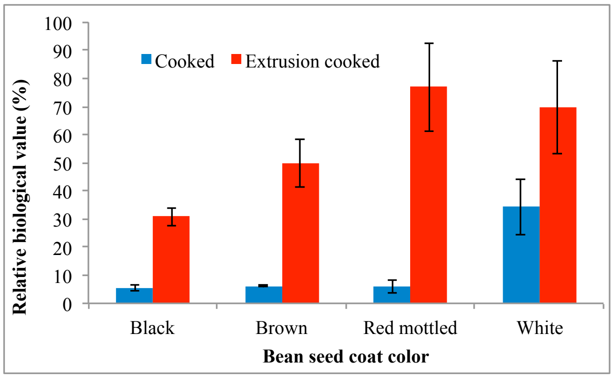
Beans are an important source of iron; however, the iron has very low bioavailability due to the high content of polyphenols and phytates, factors known to inhibit iron bioavailability. Strategies to improve beans' contribution to iron nutrition include increasing iron concentration, improving bioavailability, or increasing both. Research screened for iron bioavailability in Ugandan bean varieties and established the effects of extrusion cooking. The relative biological availability (RBA) of iron in white seed coat varieties was significantly higher than in colored seed coat varieties, indicating a need optimize process conditions in colored seed varieties (see table 2).

Variety	Color	Total polyphenol (mg/g)	Iron (μg/g)	Phytate (%)	Ferritin (μg/g)	RBA (%)
NABE 1	Red mottled	1.25 ± 0.07 ^{bc}	78.9 ± 9.2 ^{b}	1.12 ±0.16 ^{cde}	357 ± 34 ^{bcdef}	7.6 ± 2.7 ^{b}
NABE 2	Black	0.79 ± 0.05 ^{d}	62.6 ± 0.8 ^{efg}	0.50 ± 0.01 ^{def}	285 ± 36^{f}	5.5 ± 1.0 ^{b}
NABE 3	Red	1.61 ± 0.02 ^{ab}	75.3 ± 1.3 ^{bc}	0.46 ± 0.03 ^{def}	444 ± 56 ^{abcd}	6.2 ± 0.8 ^{b}
NABE 4	Red mottled	1.39 ± 0.26 ^{b}	64.5 ± 1.5 ^{e}	0.55 ± 0.13 ^{def}	479 ± 113 ^{ab}	7.6 ± 1.6 ^{b}
NABE 5	Cream/Red	1.66 ± 0.02 ^{a}	70.5 ± 2.0 ^{cd}	0.28 ± 0.01 ^{ef}	384 ± 35 ^{abcde}	8.4 ± 1.7 ^{b}
NABE 6	White	0.20 ± 0.02 ^{e}	58.9 ± 0.1 ^{fg}	0.80 ± 0.02 ^{cd}	353 ± 102 ^{bcdef}	34.3 ± 10 ^{a}
NABE 7	Red	1.42 ± 0.07 ^{b}	57.4 ± 0.6 ^{g}	0.30 ± 0.03 ^{ef}	293 ± 47 ^{ef}	8.1 ± 1.8 ^{b}
NABE 8	Red	1.26 ± 0.07 ^{bc}	79.9 ± 1.2 ^{b}	0.60 ± 0.05 ^{cdef}	390 ± 113 ^{abcdef}	9.1 ± 0.8 ^{b}
NABE 9	White/Black	1.06 ± 0.01 ^{c}	67.0 ± 1.8 ^{de}	0.25 ± 0.03^{ef}	344 ± 9 ^{cde}	5.5 ± 0.9 ^{b}
NABE 10	Red	1.60 ± 0.11 ^{ab}	64.7 ± 1.8 ^{e}	0.60 ± 0.37 ^{cdef}	293 ± 31^{ef}	6.4 ± 1.9 ^{b}
NABE 11	Cream/Red	1.25 ± 0.04 ^{bc}	65.4 ± 2.2 ^{de}	0.19 ± 0.06 ^{f}	325 ± 29 ^{def}	8.7 ± 0.9 ^{b}
NABE 12	Cream/Red	0.99 ± 0.10 ^{c}	87.3 ± 4.2 ^{a}	0.66 ± 0.01 ^{cde}	313 ± 79 ^{ef}	8.4 ± 1.0 ^{b}
NABE 13	Red	1.10 ± 0.03 ^{c}	63.5 ± 3.4 ^{ef}	1.61 ± 0.07 ^{a}	419 ± 29 ^{abcde}	9.8 ± 1.0 ^{b}
NABE 14	Red	1.76 ± 0.29 ^{a}	90.6 ± 3.1 ^{a}	1.01 ± 0.12 ^{bc}	495 ± 96 ^{a}	8.8 ± 0.7 ^{b}
K131	Brown	1.76 ± 0.15 ^{a}	67.8 ± 2.7 ^{de}	1.01 ± 0.20 ^{bc}	304 ± 95 ^{ef}	6.2 ± 0.3 ^{b}
K132	Red mottled	1.06 ± 0.08 ^{c}	75.0 ± 2.7 ^{bc}	1.31 ± 0.12 ^{ab}	470 ± 120 ^{bc}	6.1 ± 2.4 ^{b}

[a] Values are means±SD; n=4-6; Within each column, mean values with a letter in common are not significantly different from one another.

Table 2. Iron, phytate, ferritin and total polyphenol content and relative biological availability of 16 Ugandan bean varieties

The effect of extrusion cooking on iron bioavailability was also determined, with an increase in iron bioavailability in beans resulting. The optimal combination of extrusion variables was 15 percent moisture content, 120°C die temperature, and three kg/h feed flow rate.



The control was conventionally cooked by Autoclaving. Error bars represent Std Dev. n=3 extrusion reps

Graph 1. Effect of extrusion cooking on iron bioavailability of variously colored bean varieties.

Address Nutritional and Health Problems among Vulnerable Individuals through Increased Consumption of Beans, Bean Products, and Complementary Foods

We hypothesized that the availability of acceptable alternative ways of preparing beans would result in increased bean consumption. Phase II analyzed consumers' sensory, culinary, and processing requirements and informed national breeding programs. Key Phase II activities involved developing and utilizing appropriate extension information education and communication (IEC) approaches (nutrition, processing of bean based products) for rural community nutrition and health workers to accelerate and multiply positive rural development impacts.

In Uganda and Rwanda, manuals and posters on improved methods of bean preparation (soaking and germination) that enhance cookability and nutrient bioavailability were developed, as was a manual on feeding children aged 6–59 months that increased awareness of the benefits for children of adequate feeding practices. Another manual explained the preparation of porridge for the very young using bean-based composite flour.


Village Food Prep.


Baked-Fried Foods

In Rwanda, training at the community level covered nutrition and its relationship to health, bean flour pretreatments and processing, bean-based soup processing, and utilization of simple cold extrusion technology (using hand-operated presses) with processed beans and maize.

Analyze Varieties' Culinary Properties, Sensory Characteristics, and Consumer Acceptability

Culinary and sensory properties of 18 improved varieties in Uganda were screened to inform the breeding programs regarding consumer acceptability. Overall, the local varieties were significantly preferred in terms of color, texture, flavor, and taste compared to the improved varieties, while improved beans cooked in a shorter time and showed higher protein but lower zinc content.


Village Taste Test

Farmers were trained in preparing the cold extruded bean snack and soaking and sprouting to enhance nutritional quality of bean dishes for children younger than five years.

A *Letter of Agreement* was signed in 2012 between CIAT/PABRA and Makerere University to implement activities leading to the improvement of food and nutrition security for vulnerable communities, specifically value-added bean products, new recipes using processed bean products, and the sensory qualities of new products. An agreement was signed in 2013 between CIAT and IFPRI on behalf of the Harvest Plus Challenge Program Phase II and Makerere University to increase the nutritional benefits of products from iron-enhanced beans by children and women of reproductive age. Work will determine the influence of extrusion processing on protein and carbohydrate digestibility and micronutrient bioavailability, especially of iron and zinc, and develop a bean-based snack and breakfast cereal.

Incorporate Insights from Analysis of Private Food Processing Industry Regarding Development and Commercialization of Bean-based Products

The project team established a partnership with the private business sector to promote adoption of value addition to increase bean consumption and create new market outlets. Bean varieties that are high yielding and stress resistant but have low consumer acceptability and are prone to being hard to cook were selected for value addition and product development. Private sector partners are now better linked to farmer organizations for value-added activities.

Bean flour production was piloted in Makerere University's Food Technology and Incubation Centre with Nutreal Ltd. Sales are growing as consumers try the flour. Appropriate packaging, marketing, and promotion materials have been developed and tested.

Farmers have been prepared to be suppliers through collective marketing by teaching them postharvest techniques to maintain the quality of their beans. Increased quantities of Kamuli farmers' beans are being sold to Nutreal for processing.

To Identify Solutions for Constraints to Increased Marketing and Consumption

Farmers in Kamuli own and cultivate 1½–3½ acres, and one-half borrow or rent one acre for their agricultural activities. Although most households sell some agricultural produce, initially, only 15 percent of farmers were harvesting even 50 kg of beans. Currently, project households have increased the area planted in beans by 50 percent and increased market participation in beans to 65 percent. Improved crop management practices and technologies have stimulated market participation and increased the quantity available for sale (median sale, 50 kg). Proper drying, sorting, grading, and storage have also helped improve quality, demand, and price.

Community-based production of quality seed ensures seed availability when farmers are ready to plant.

The project in Uganda has strengthened the collective marketing capability of farmer groups through improved understanding of market price variations, postharvest handling, and negotiation skills, and better coordination of community grain bulking and storage. Market price boards in all VEDCO operation areas display market prices for crops and are updated weekly. Cell phone messages also inform farmers about market prices. The project assisted farmer groups in developing business plans, improving record keeping and analysis, promoting gender equity and group dynamics, and learning from successful farmers and seed production groups.

A multistakeholder bean value chain forum (farmer marketing groups and associations, government agencies, NGOs, private traders, transporters, distributors, and processors) has been established to enable participants to identify key constraints and solutions for broad-based, successful market participation. As a result, bean farmers have established stronger links with traders, and input traders have extended their services to farming communities and provided advisory services. Through VEDCO's partnership with AGRINET, bean farmers are now accessing information on market prices from the different regional markets and the bean varieties in high demand.

Participating in the Pulse CRSP project has enhanced farmers' assets and capabilities, individually and collectively. Their social capital has been enhanced through strengthening their groups and connections with other groups; their human capital through technical knowledge and application; their political capital through leadership roles and awareness of their interests and rights and capabilities of lobbying local government officials for support of their initiatives; their natural capital through increased land cultivation; their physical capital through high yielding, improved bean varieties tolerant to environmental stresses.

POTENTIAL DEVELOPMENTAL OUTCOMES AND BENEFITS TO PULSE VALUE CHAIN(S)

Capacity building training with six farmer research groups covered critical management practices and technologies, from preplanting to postharvest handling. Community-based production of quality seed ensures seed availability. Extension materials have provided training and improved bean variety seeds to 1,000 farmers (70 percent women) in 60 demonstration sites.

The public–private partnership between Makerere University and Nutreal Ltd. developed and promotes nutrient-enhanced and shelf-stable, bean-based products sold in Kampala's supermarkets. Kamuli farmers' beans are being sold to Nutreal for processing. Porridge has been developed for supplementary feeding. In Rwanda, KIST is exploring collaboration with Africare and World Vision for widespread utilization. Farmers and health workers have new ways to prepare beans in home meals and rural microenterprises. Establishing the bean value chain stakeholder forum has fostered mutual understanding among farmer marketing groups and associations, government agencies, NGOs, private traders, transporters, distributors, and processors.

CONTRIBUTIONS TO INSTITUTIONAL CAPACITY BUILDING

Four host country partner organizations and Iowa State University have benefitted from engagement in applied multidisciplinary research and development activities. Makerere University has been able to train and mentor five M.Sc. and undergraduate students in food technology and nutrition, agricultural extension and innovation, and agricultural economics. Two students from Uganda completed their Ph.D.s at Iowa State University in Food Science and Human Nutrition, and Crop Physiology and Sustainable Agriculture in 2012 and 2013, respectively.

Uganda's National Crops Resources Research Institute has collaborated with researchers at three universities and at VEDCO. With supplement project funding, consistent capacity building activities in Kamuli were guided from Makerere University. VEDCO's staff and community-based trainers learned advanced methods of farmer learning facilitation, and many farmers learned improved practices. The supplemental funding also helped scale up innovative management practices and technologies to wider populations in Uganda. KIST has trained one M.Sc. student and many B.Sc. students in food science and technology research. Cumulatively, the project team has mentored 27 students (13 female) for degree training, seven at the graduate level and 20 at the B.S. level.

Short-term training for 67 farmers (58 women) has been conducted in Kamuli. Other members of their six farmer groups (20–25 members each) also participated in training sessions, according to their respective interests. Bean crop management practices and technologies have been directly disseminated to approximately 1,000 households. Farmers' marketing associations in two subcounties are directly benefitting from project activities. We provided technical assistance directly to 82 community-based organizations; women constitute the majority of their members.

KEY PUBLICATIONS

Mazur, Robert. (2012). Improving production, nutrition, marketing and livelihoods – bean value chain research and development in Uganda. Paper being prepared for submission to *Food Policy*.

Mutambuka, M, Hendrich, S, Reddy, MB, Lamsal, PB, Hui, W, Murphy, PA (2012). Optimization of white common beans (*Phaseolus vulgaris*) extrusion cooking process. Paper being prepared for submission to *Journal of Agricultural and Food Chemistry*.

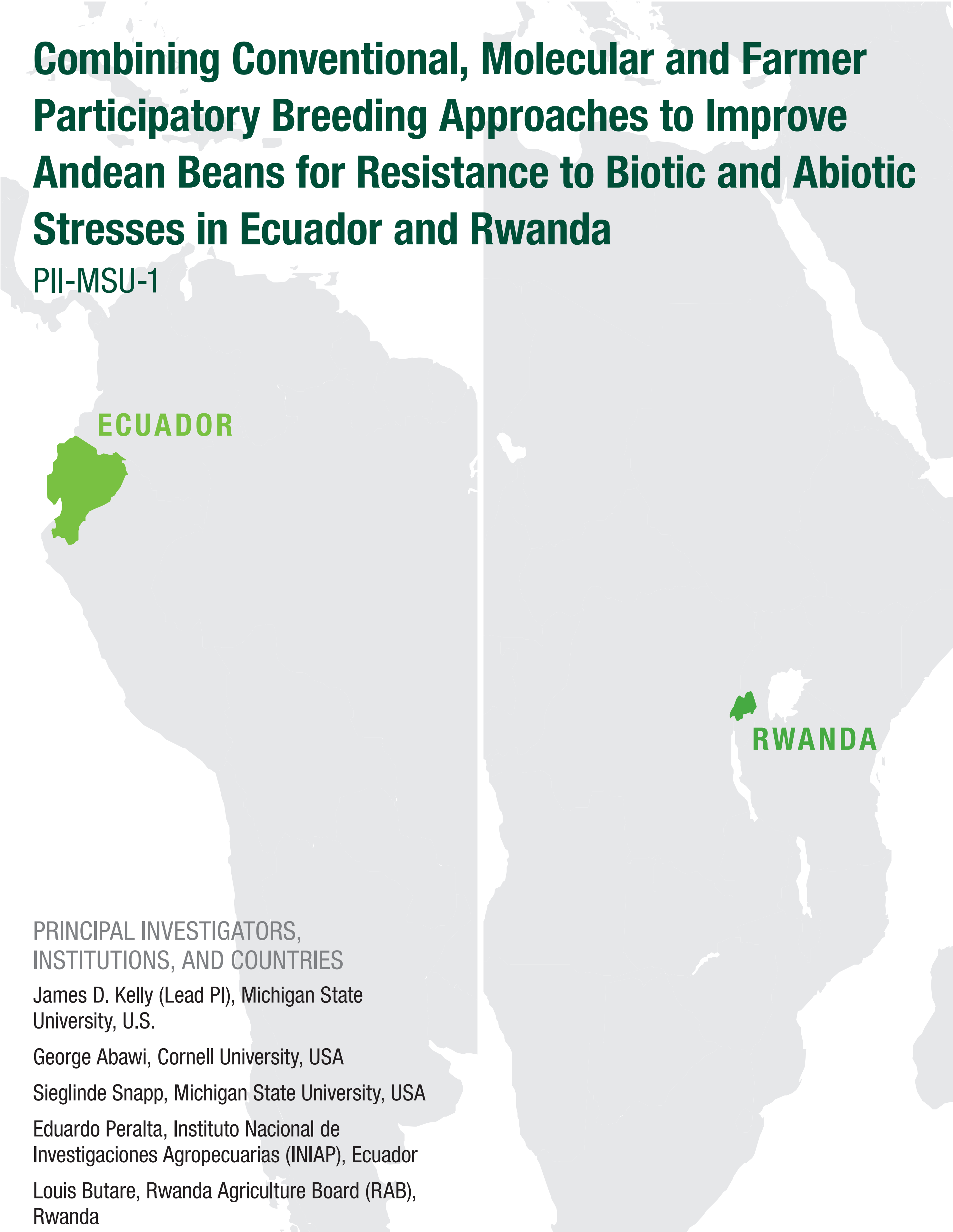
Mutambuka, M, Murphy, PA, Hendrich, S, Reddy, MB (2012). White common beans (Phaseolus vulgaris) have higher invitro iron bioavailability than colored seed coat varieties. Paper being prepared for submission to *Journal of Agricultural and Food Chemistry*.

Ndagire Tamale, Catherine (2012). Optimized formulation and processing protocol for a bean-based composite flour. Paper being prepared for submission to *Journal of Nutrition and Food Sciences*.

Sebuwufu, G, Mazur, R, Westgate, M, and Ugen, M (2012). Genotype and soil fertility interactions on yields of common beans (*Phaseolus vulgaris* L.) grown by smallholder farmers on nutrient depleted soils in southeastern Uganda. Paper being prepared for submission to Agronomy Journal.

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

PII-MSU-1



PRINCIPAL INVESTIGATORS, INSTITUTIONS, AND COUNTRIES

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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

A major effort of the project was to support and expand bean breeding activities in Ecuador, Rwanda, and Michigan. The project has achieved this goal in a number of different ways, including the release of 27 varieties, sustained and expanded breeding activities in Ecuador and Rwanda through farmer participatory breeding activities, with an emphasis on gender, germplasm exchange between programs, personnel training, workshops, graduate training, and the future integration of the new molecular technologies through the BeanCAP project in the United States. At the termination of the project, the national programs in Ecuador and Rwanda are actively breeding and releasing new varieties and are on a path to sustainability with these vital, long-term breeding programs. Two doctoral students conducted research in Rwanda and will graduate in August 2013. One master's student conducted research in Ecuador and graduated in August 2012.

PROBLEM STATEMENT AND RESEARCH APPROACH

Common bean is the most important grain legume consumed in Ecuador and the most important protein source in Rwandan diets. Approximately 120,000 hectares of beans are cultivated annually in Ecuador, and common bean is the most widely grown pulse in Rwanda (300,000 hectares). Both bush and climbing beans constitute an important income for farmers and staple food for thousands of Ecuadorian families and the vast majority of small-scale farmers in Rwanda. Beans occupy 20 to 31 percent of cultivated land in Rwanda and are grown by almost 95 percent of farmers in all the major regions of the country. Rwanda has the highest per capita bean consumption in the world, exceeding 40 kg.

Improvement of bean genotypes for Ecuador's environments has had a significant spinoff in its adaptation to Rwanda's upland farming systems. Climbing beans have been adopted by households across a range of different farm sizes, gender, and economic classes, and production has increased significantly from mineral fertilizer residues from crop rotation with maize. Drought-tolerant climbing bean varieties have been released recently in Eastern province and contribute to the increased productivity of beans in this drought prone area. The yields are three to four tons per hectare for climbers versus 1.5 to two tons for bush beans.

Beans are more vulnerable to abiotic stresses, including drought, heat, and low soil fertility, and biotic stresses, including attacks by diseases and insects. Breeding for disease resistance is a key element in the successful boost of bean productivity in both Rwanda and Ecuador. The important diseases of beans are angular leaf spot, anthracnose, ascochyta blight, and root rot; root rot is caused by a complex of soil pathogens, particularly *Pythium*, *Fusarium*, and *Rhizoctonia* species. Smallholder Rwandan farmers, many of them widows supporting families, are keenly interested in rebuilding their bean genetic stocks and expanding into new markets. Building on international bean germplasm, but particularly on the Ecuador experience and germplasm, a valuable opportunity to develop and deploy improved bean varieties in Rwanda has been embraced, using the latest molecular and client-oriented plant improvement techniques. An improved understanding of plant traits and genotypes with resistance to multiple stresses from abiotic and biotic sources has provided unique materials for small-scale farmers along with insight into plant tolerance mechanisms to enhance plant breeding methods.

ACHIEVEMENTS AND OUTPUTS

Variety Releases

Michigan

The bean breeding program in Michigan continues to focus on breeding a wide array of commercial seed types. Over the project's five-year period, the bean breeding program at Michigan State

University (MSU) released seven new varieties in six different commercial classes, including *Zorro* black, *Santa Fe*, and *Eldorado* pinto, *Rosetta* pink, *Bellagio* vine cranberry, *Snowdon* white kidney, and *Fuji* otebo bean varieties. Certified seed of all new varieties is available to commercial growers through the Michigan Crop Improvement Association.

Zorro is a high-yielding black bean with moderate resistance to common bacterial blight and excellent canning quality; its adoption rate was 80 percent of black bean planted in Michigan and has reduced production costs due to upright architectural developments. An education video on the role of plant breeding to solving growers' needs highlights this advanced plant architectural trait (http://www.youtube.com/watch?v=wf_nOs7DP-o).

In pinto beans, *Eldorado*, released in 2012, is the highest yielding variety developed at MSU. It combines high yield and upright architecture with resistance to white mold. *Rosetta* pink, which combines high yield and upright architecture but is not susceptible to breaking in high winds as was *Sedona*, was released; it will replace Sedona.

Releases were also made in three specialty bean classes. Snowdon is a high yielding, early maturing white kidney bean targeted to replace *Beluga*, which it has outyielded by 17 percent. *Bellagio* was released to meet the standards of the Italian canning industry and is expected to contribute to resurgence in cranberry bean production in Michigan. Fuji was developed using marker assisted selection for resistance to bean common mosaic virus to meet a production need in Otebo beans going to markets in Japan. Fuji is contributing to expanded production of this specialty bean class in Michigan and Ontario.

Ecuador

The program in Ecuador is now releasing varieties from breeding lines developed exclusively by the research team in INIAP. The program has progressed from releasing varieties from introduced lines to crossing introduced lines to now having its own stable of breeding lines adapted to local conditions and with competitive quality characteristics. The most recent varieties represent a genetic pyramid of resistance genes that did not previously exist.

Over the five-year period of the project, the bean breeding program at INIAP released seven new varieties in four different commercial classes: four varieties with large red mottled seed: *INIAP 430 Portilla*, *INIAP 481 Rojo del Valle*, *INIAP 483 Intag*, and *INIAP 484 Centenario*; a purple mottled seed type, *INIAP 429 Paragachi Andino*, for green shell; yellow Canario seed type *INIAP 480 Rocha*, and a black seeded *INIAP 482 AfroAndino*. Paragachi Andino and AfroAndino were introduced breeding lines; the other five were developed through breeding and selection programs. All the varieties were released through evaluation and participatory selection with farmer members of the CIALs in the northern provinces of Carchi, Imbabura, and Intag. Small seed storage and cleaning plants were established to handle seed production in the different valleys.

Portilla was bred to possess a larger plant, with improved vigor and stress tolerance but lacked adequate disease resistance. Rojo del Valle was developed as an upright indeterminate rather than a bush type better suited for green shell production. Rojo del Valle carries intermediate resistance to rust and high levels of resistance to root rot. Intag is the first to possess resistance to three important foliar diseases—rust, anthracnose, and angular leaf spot—and is impacting a broad area of the Intag Valley. Centenario carries resistance to four diseases—angular leaf spot, anthracnose, rust, and *Fusarium* wilt and has outyielded Portilla by 39 percent.

Rocha canario bean was bred for improved yellow seed color, better emergence, and rust resistance; it matures two weeks earlier than Canario del Chota and has a high number of pods per plant and exhibits a high emergence rate. In the purple mottled seed class, Paragachi Andino was released principally for the green shell market. It has a round seed and indeterminate growth habit with additional anthracnose resistance. The Afroandino variety is a small seeded black bean and is good for adaptation, yield, seed quality, and root rot resistance. It was released by INIAP for direct consumption and use in the local canning industry. Seed production of all new varieties is being managed by INIAP through selected seed growers in the major production areas.

Rwanda

The breeding program in Rwanda released nine bush bean and 13 high-yielding climbing bean varieties with varying levels of disease and stress resistance and nutrient content in a number of diverse market classes for production in a wide range of ecological zones (see table on p. 15). Six early-season bush bean varieties with four distinct seed types were targeted for the low to mid altitude regions of the country. The new varieties represent a range of seed colors and all are derived from the Andean gene pool. In addition, the program released three small seeded red bean varieties—*SER 13*, *SER 16*, and *SER 30*—with indeterminate habit and enhanced drought tolerance for regions in eastern Rwanda. The SER lines come from the Mesoamerican gene pool. Bush beans yield up to two tons per hectare, whereas climbing beans have a potential yield of three to 4.5 tons per hectare, so the program has worked with CIAT to develop the MAC (mid-altitude climbers) lines to further enhance bean yields in lowland production regions. Three lines with red-mottled Calima types—*MAC 9*, *MAC 44*, and *MAC 49*—were released and are under seed increase. Five high-yielding climbing varieties in a range of seed types suited to local markets were released, possessing a range of disease-resistance traits. The program has also been developing biofortified lines with higher levels of iron and zinc; five of these high-yielding, climbing have seed iron levels above 85 ppm. Basic seed production of all new varieties is being conducted by RAB on research stations, and that seed is distributed through community networks, NGOs, and farmer associations to small producers throughout the country.

POTENTIAL DEVELOPMENTAL OUTCOMES AND BENEFITS TO PULSE VALUE CHAIN(S)

- The program has developed a second mapping population to use for screening for drought in large seed red/red mottled seed types that are highly acceptable in Rwanda and Ecuador. The *RAB651/* Concepcion* inbred backcross line (IBL) population, developed in Ecuador, was evaluated for drought resistance in Rwanda. The evaluation of 72 IBL and checks was conducted in Karama dryland station under rain-fed and irrigated conditions in Rwanda. There were no significant differences in seed size, number of days to flower, and number of day to maturity between water regimes. Yield, however, was significantly reduced by drought stress, since there was a 21 percent yield reduction in rain-fed plots compared to the irrigated plots. Certain genotypes were identified as high yielding regardless of water treatment. Seed is available in Puerto Rico and in Rwanda for further evaluations under drought stress.

- A new rust strain characterized as race 22:2 that defeats many of the current resistance genes deployed in Michigan has been confirmed over the last five growing seasons. Given the persistence of this race, an extensive screening of all MSU germplasm has been conducted and resistance appears to be associated with the Ur-5 locus on chromosome Pv04. Resistance is currently being integrated into black, navy, small red, and pinto bean classes.

- Five new races of rust—9:0, 12:0, 28:0, 61:0, and 60:0—were identified from five samples collected in the five villages in Ecuador and are Andean in origin. Concern exists that many of the resistance sources have been defeated. The *Ur 3*$^{+}$ gene from Mexico 235 was the only gene that showed full resistance to all isolates characterized to date. The *Ur-11* gene from PI181996 was attacked by a single isolate identified as race 53:63. Other genes have shown compatibility with either three or more rust isolates characterized.

Table 1. New Bush and Climbing Bean Varieties released in Rwanda in 2010

Name	Origin	Maturity (Day)	Yield (T/Ha)	Seed size	Color	Adaption Zone	Reaction to principal diseases				
Bush beans							ALS	ANT	BCMV	RR	ASC
RWR 1180	RAB	75	2.0	Large	Red mottled	Low - Mid	I	R	R	R	I
RWR 2245	RAB	80	2.5	Large	Red mottled	Low - Mid	I	R	R	R	R
RWR 1668	RAB	85	2.0	Large	Red	Low - Mid	R	R	R	R	R
RWR 2076	RAB	80	2.0	Large	Red	Low - Mid	I	R	I	R	R
RWR2154	RAB	80	2.0	Large	Sugar	Low - Mid	I	R	R	R	I
R617-17A	RAB	85	2.0	Large	Grey-Cream	Mid - High	R	R	R	R	R
Climbers for mid and high altitude, 1500-3000 masl											
RWV 2070	RAB	110	4.5	Large	Pink	Mid - High	I	R	R	R	R
Gasirida	RAB	110	4.5	Large	Purple	Mid - High	I	R	R	R	R
Climbers for mid altitude, 1500-2500 masl											
RWV 1129	RAB	100	3.5	Large	Mwezi-moja	Mid	I	R	R	R	I
RWV 1892	RAB	100	4.0	Medium	Red	Mid	R	R	R	R	I
MAC 28	CIAT	90	3.5	Medium	Calima	Mid	I	R	R	R	I
Climbers for low altitude, under 1500 masl											
MAC 9	CIAT	85	3.0	Medium	Calima	Low	R	R	R	R	I
MAC 49	CIAT	84	3.0	Medium	Calima	Low	I	R	R	R	I
MAC 44	CIAT	86	3.5	Medium	Calima	Low	R	R	R	R	R

ALS= Angular leaf spot; ANT=Anthracnose; BCMV=Bean Common Mosaic Virus; RR=Root Rots; ASO=Ascochyta; R=Resistant, I=intermediate resistance; Yield in metric tons per hectare; masl=meters above sea level. Large seed weigh over 45g 100seeds-1; Medium weigh 30-44g 100seeds-1; Calima types are red mottled seed

Table 2. Drought tolerant red seeded bush bean varieties released in Rwanda in 2010

ALS= Angular leaf spot; ANT=Anthracnose; ASO=Ascochyta; BCMV=Bean Common Mosaic Virus; CBB=Common bacterial blight; RR=Root Rots; 1=Highly resistant, 2=moderate resistant, 3=intermediate resistant; Yield in metric tons per hectare

Variety	Yield (t/ha)	Seeds/ pod	Number of pods/plants	Reaction to principal diseases					
				CBB	BCMV	ALS	ANT	ASC	Rust
SER 13	2.0	6	30	3	1	3	1	1	3
SER 16	2.2	5	33	3	3	3	1	2	3
SER 30	2.0	5	25	3	3	3	1	3	2

Table 3. New biofortified Climbing Bean Varieties released in Rwanda in 2012

DF=Days to Flower, DM=Days to Maturity, L=large seed size, M=medium seed size; Large seed weigh over 45 g 100seeds-1; Medium weigh 30-40g100 seeds-1; Yield in metric tons per hectare; Sugar types are cream with red mottle equivalent to US cranberry bean

Variety	Origin	Pedigree	DF	DM	Seed color	Seed size	Fe ppm	Zn ppm	Yield (t/ha)
RWV3317	Local cross	NGWIN x CAB2/2/3/1/1	56	110	Red	L	95	28	4.0
RWV 3316	Local cross	CAB2 x LAS400	58	110	Red	L	92	31	4.0
MAC 42	CIAT		35	80	Sugar	M	88	45	3.5
RWV2887	Local cross	AND x Mwizarahenda	56	108	Sugar	L	88	29	4.2
RWV 3006	Local cross	CAB2 x Buberuka	58	110	White	L	90	37	3.8

- Twenty-three isolates of anthracnose from Ecuador have been characterized and 17 races 1`1` were identified, the most virulent races being 423, 429, and 813. The *Co-3* gene from Mexico 222 and the *Co-4*^{2}*, Co-5*^{2}*, Co-7* genes from G2333 were the only ones that showed full resistance to all isolates characterized. Only races 27 and 55 of anthracnose have been identified in Rwanda.
- A new screening system has been developed in Ecuador for angular leaf spot (ALS). Six samples of ALS collected in the different villages were characterized and three races, 62:0, 30:0, and 31:3, were identified; race 31:3 is the most virulent and race 62:0 the most common.
- Surveys were completed in both Rwanda and Ecuador to determine the prevalent root diseases of beans and their causal soil borne pathogens. The prevalent pathogens identified varied among the production regions in both countries and included *Fusarium solani f. sp. phaseoli, F. oxysporum f. sp. phaseoli*, *Rhizoctonia solani*, *Macrophomina phaseolina*, *Sclerotium rolfsii*, and *Meloidogyne spp*. (root-knot nematodes). In addition we confirmed the extensive involvement of insect pests (stem borers, bean fly, etc.) and their interference with root rot evaluations and germplasm selection, thus promoting the need for their effective control in root rot evaluation nurseries. Annually, large numbers of bean breeding lines and varieties from the breeding program of Drs. Kelly and Porch and others were evaluated for root rot resistance under field and greenhouse conditions in New York. Results from these evaluations showed a high level of tolerance to root pathogens in several breeding lines and new varieties that have been advanced and released.
- The scarcity of staking materials remains a big challenge for the adoption and expansion of climbing beans to newer farmers. Validation and demonstration trials of six different options for staking climbing beans were conducted at seven different sites. Through participatory evaluation, all the farmers chose the option that reduces staking wood from the recommended 50,000 to 16,700 per ha that were reinforced with strings and cords.

CONTRIBUTIONS TO INSTITUTIONAL CAPACITY BUILDING

Doctoral Dissertations

Mukeshimana, Gerardine. 2013. Dissecting the genetic complexity of drought tolerance mechanisms in common bean (*Phaseolus vulgaris l.*)

Citizenship: Rwanda; Major Professor: Dr. J.D. Kelly; Graduation: 2013

Among the abiotic stresses that limit plant growth and productivity, drought is the most complex and devastating on a global scale. With expected frequent, severe, and widespread droughts, crops with greater ability to adapt to reduced water use are needed to cope with the changing environment and more severe drought conditions. Studies were designed to evaluate an inter-gene pool recombinant inbred line bean population from a cross of SEA5 and CAL96 and identify quantitative trait loci (QTL) linked to drought resistance in the field, identify shoot traits associated with drought resistance in bean seedlings, and identify factors influencing regeneration and *Agrobacterium tumefaciens*-mediated transformation of common bean.

Isaacs, Krista. 2013. Bean and maize genotype by cropping systems interactions and farmer knowledge in the rapidly changing agricultural landscape of northern Rwanda,

Citizenship: United States; Major Professor: Dr. Sieglinda Snapp; Graduation: 2013

Traditionally, Rwandan farmers plant multiple crops each season, often in mixtures with two to five different crops in the same field. A newer agricultural policy in Rwanda, PSTA II, encourages land consolidation and, in our field sites in northern Rwanda, urges farmers to grow bean monocultures in season B and maize monocultures in season A. Our cropping system experiment results indicate that these are appropriate seasons for each of these crops when we consider grain yield. By varying factors depending on location, beans yield higher in season B, and maize yields higher in season A. However, there are multiple methods to evaluate cropping systems performance, and some of these may be more relevant to subsistence farmers who grow the majority of their crops for consumption and have minimal surplus and/or access to markets.

Based on the comparison of both protein/kg and price scenarios, subsistence farmers may benefit more from growing both crops each season in monoculture or intercropping.

In the variety x cropping system analysis and farmer participatory variety selection, we found significant season x environment interactions. Bean varieties that yielded the highest in monocrop or intercrop varied by location and beans yielded twice as much in a monocrop compared to an intercrop with maize. There were no significant differences in maize yields between the two cropping systems. Results indicate that different varieties perform well in different niches, and the best yielding variety in the monocrop is not always the best yielding variety in the intercrop. In addition, farmers' preferences for these varieties did not always correspond with the highest yielding variety.

Master's Thesis

Jablonski, Sara. 2012. The nature of participation in Ecuador's participatory bean improvement program

Major Professor: Dr. Kimberly Chung; Graduation: 2012

Across Latin America, local agricultural research committees (CIALs) have been highly successful at creating forums in which farmers and researchers jointly diagnose problems and collaborate on applied agricultural research. Collaborating with local farmers is expected to improve the relevance of agricultural research for local communities, increase farmer capacity for research, and increase the potential for technology adoption. However, implementing the CIAL methodology requires participatory processes and a high level of commitment to facilitate. This thesis reports on a case study that explores how Ecuador's national bean breeding program (INIAP) has implemented the CIAL methodology as part of the participatory plant breeding approach to identify new varieties best suited to different production regions and recommends how the breeding program can better achieve its research objectives by committing to a higher level of engagement with CIAL communities.

Short-term training

Louis Butare, bean breeder and program leader from Rwanda, visited the breeding program in Ecuador during November 2008 to study INIAP labs and field facilities and nurseries, visit different CIALs where cooperative work is underway, and study the participatory research approach and seed multiplication strategies currently working in Ecuador. Experience from that trip has been applied to bean staking studies in Rwanda and a number of new lines and varieties from Ecuador are being trialed in Rwanda.

Workshops

Drs. J. Kelly and G. Abawi conducted a three-day workshop on bean pathology (major root and foliar diseases) and breeding/genetics of beans for 23 RAB technical staff in Rubona, Rwanda, in May 2011. Visual aids and PowerPoint information were distributed to the participants to provide a better understanding of these scientific fields and the role the science played in the then-current project. The workshop included field trips to collect and isolate different pathogens.

A workshop entitled *Participatory Research Methods Workshop: Client-Oriented Plant Breeding and Agronomy* was held for 33 participants—largely from RAB and NGOs working in Northern Rwanda—in February 2012 at the RAB Research Station, Musanze. Participants gained an understanding of theory and new methodologies in participatory breeding and agronomy for improved bean-based farming systems. Focus areas included trial designs, participatory educational approaches, participatory plant breeding case studies from Malawi and Ecuador, and practical tools for field research and support of sustainable livelihoods.

A molecular breeding workshop was conducted in the biotechnology lab at Musanze in February 2012. Fifteen participants, including 13 from RAB's bean research program and two students from Umutara Polytechnic doing their research work under the Pulse CRSP project in Nyagatare attended the course. The first day was reserved for theory on molecular plant breeding and its application while the second day was reserved for the hands-on sessions. Various topics, including theories on importance and steps of marker-assisted selection, QTL analysis, DNA extraction, PCR, and DNA electrophoresis were covered. Participants learned the use of DNA markers that are tightly-linked to the target loci as a substitute to assist phenotypic screening through MAS to speed-up breeding and selection for different traits.

KEY PUBLICATIONS

Kelly, J.D., G.V.Varner, P. O'Boyle and B. Long. 2009. Registration of "Zorro" black bean. *J. Plant Registrations* 3:226–230.

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.

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

Kelly, J.D., G.V. Varner, W. Mkwaila, K.A. Cichy and E.M. Wright. 2012. Registration of "Eldorado" pinto bean. *J. Plant Registrations* 6: 233–237. doi: 10.3198/jpr2012.02.0140crc.

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.

PLANT VARIETY PROTECTION CERTIFICATES

Plant Variety Protection Certificate No. 201000268 was issued for Zorro black bean variety on 8/18/2011.

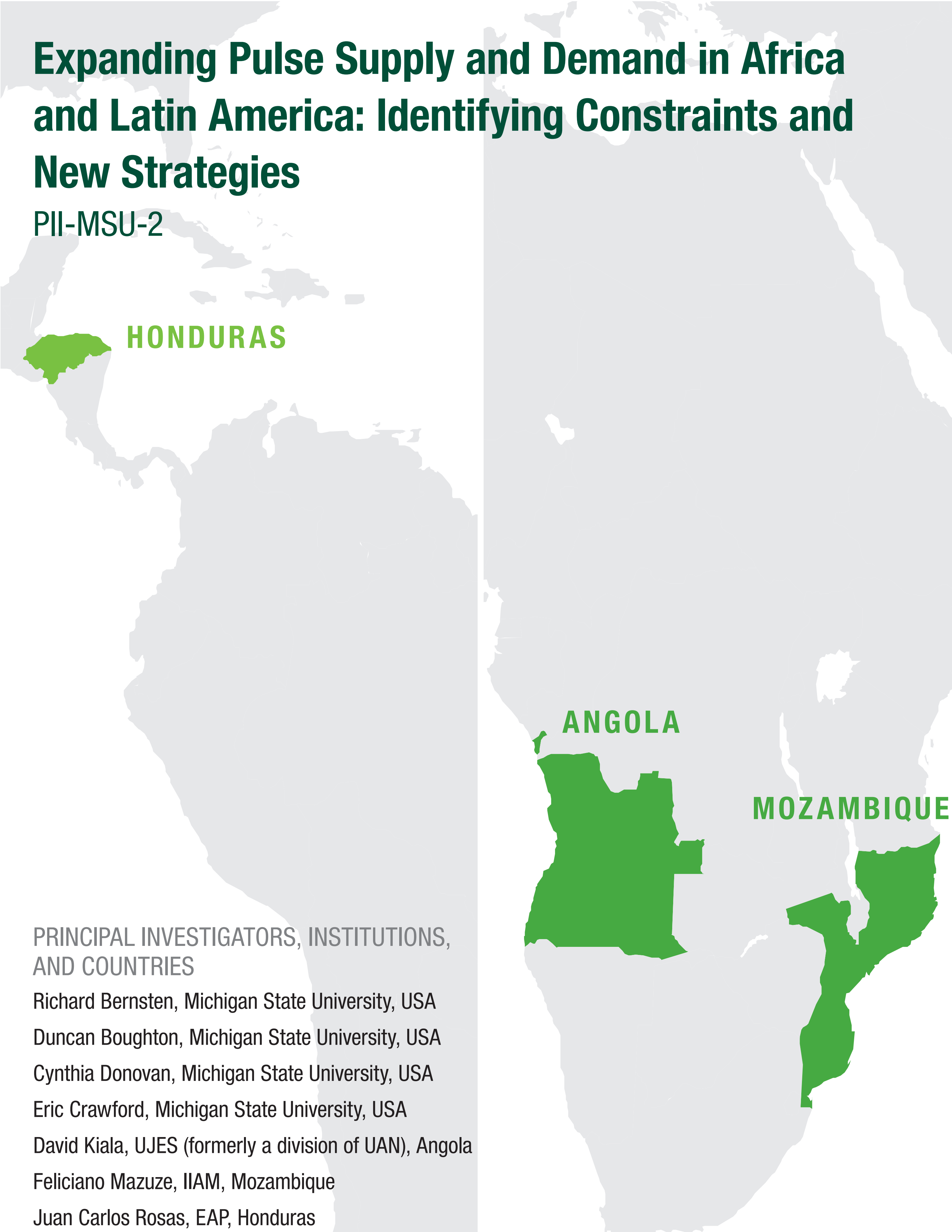
Plant Variety Protection Certificate No. 201000269 was issued for Santa Fe pinto bean variety on 8/18/2011.

Plant Variety Protection Certificate No. 200700410 was issued for Sedona pink bean variety on 4/7/2008.

Plant Variety Protection Certificate No. 200700411 was issued for Capri cranberry bean variety on 4/7/2008.

Expanding Pulse Supply and Demand in Africa and Latin America: Identifying Constraints and New Strategies

PII-MSU-2



PRINCIPAL INVESTIGATORS, INSTITUTIONS, AND COUNTRIES

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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

This project was implemented in Angola, Mozambique, and Honduras. The research in Angola used a value chain approach to evaluate the key factors affecting the competitiveness of domestic dry beans and cowpeas. The project supported both an M.S. degree student and several short-term trainings for staff and students at the University of Jose Eduardo dos Santos. Research results highlight leverage points to reduce costs and/or improve the value to consumers in a coordinated manner.

In Mozambique, beans and cowpeas have considerable production potential and play an important ecological role in specific agroecologies, but yields are low and postharvest losses are high. Researchers at the Mozambican Institute for Agricultural Research (IIAM) identified the lack of information and analysis to improve the performance and sustainability of bean and cowpea value chains as key constraints. Researchers identified potential opportunities and resolved constraints in the value chain, from production to marketing.

In Honduras, 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 and evaluated sustainable production technologies (e.g., organic fertilizers, pest and disease control practices) and trained farmers and NGO personnel how to produce these technologies.

PROBLEM STATEMENT AND RESEARCH APPROACH

Angola

In postwar Angola, smallholder agriculture is beginning to shift from a subsistence orientation to more market-oriented production, and investments are being made into developing markets. Dry beans and cowpeas may be high potential commodities for Angolan smallholders, both for local markets and for supermarkets in high consumption regions, although local beans and cowpeas will have to compete in price and quality with imported beans.

Research in Angola evaluated the key factors affecting the competitiveness of domestic dry beans and cowpeas. Results highlight leverage points to reduce costs and/or improve the value to consumers.

Mozambique

The majority of rural households in Mozambique still experience persistent, deep poverty and high levels of food insecurity. After groundnuts, beans, which along with cowpeas have considerable production potential and play an important ecological role in specific agroecologies, are the most important legume crop grown in Mozambique in value terms; however, yields are low and postharvest losses high. Researchers at IIAM identified lack of information and analysis to improve the performance and sustainability of bean and cowpea value chains as key constraints.

Researchers used a value chain approach to identify potential opportunities and resolve constraints in the value chain, from production to marketing. Household and market price data were analyzed and farmer and trader focus groups were held to raise the incomes of rural households engaged in bean and cowpea production and marketing, and to increase the availability of marketed surpluses for domestic consumption and export to neighboring countries. Collaboration with the agricultural market information system (SIMA) involved price and market analysis as well as assistance in developing a cell phone system for market information on beans, cowpeas, and other staple foods. Private sector linkages and a task force approach were used to better link farmers to markets.

Honduras

Sustainable Bean Production

Bean production in Central America is conducted by small-scale farmers on less-than-three-ha farms, mainly on hillsides with marginal soils. Diseases, pests, drought, and low fertility limit bean productivity because the majority of these resource-poor farmers have very limited access to fertilizer, irrigation facilities, and good quality seed of resistant cultivars. Nonetheless, progress on increasing bean productivity has been made by developing and disseminating improved resistant cultivars along with local production of good quality seed; still, many pests and poor soil fertility limit the yield potential of these improved cultivars in many areas.

Sustainable bean production utilizing management practices based on the local production and utilization of organic fertilizer from recycling farm residues and waste and pest control products using plant extracts and household items were tested under this project.

Various practices for managing bean crops using organic fertilizers (e.g., bokashi and compost, produced with chicken manure, crop residues), household items (soap, oil, ethanol), and plant extracts (*Gliricidia*, nim, hot pepper, garlic, parsley) that have proven effective in reducing insect pests and disease incidents were tested and disseminated in fields in the Yojoa Lake, Yorito-Sulaco-Victoria, and Vallecillo. *Rhizobium* inoculation trials and commercial plots were also established. Similar trials were also conducted in the southern and western bean production regions of Honduras.

NGOs' technical personnel and farmer CIAL leaders received training on producing organic fertilizer and pest control products at Zamorano's Organic Agriculture Unit. They then trained other farmers in their communities. Facilities for producing organic fertilizer and pest control products were established, and practical courses and demonstrations provided. Field trials and demonstration plots helped promote these products.

Fair Trade

Most small-scale farmers sell their beans to middlemen soon after harvest and receive a low price because the market is flooded. If bean farmers become third-party certified producers of fair trade beans and marketed them to an upscale U.S. food retailer, they would receive a fair price equal to their costs of production plus a 10 percent price premium.

This study sought to determine if there were a demand for fair trade beans among upscale U.S. food retailers; identify the steps required for farmers to receive third-party certification as producers of fair trade beans; document the supply chain from the farm gate to the U.S. retailer, including the costs associated with each stage of the supply chain; negotiate a purchasing contract (quantity, price, quality standards, and shipment date) with an upscale U.S. food retailer; and organize farmers to produce and deliver a shipment of fair trade beans to a U.S. food retailer. The project was initiated in October 2009.

In Honduras, PIs met with farmers in the Yoro Lake region who were members of a farmers' association to explain the initiative and to identify farmers interested in producing fair trade beans; these PIs then met with Honduran government officials, wholesalers, exporters, and USDA/APHIS staff to identify the stages of the supply chain and the requirements at each stage. Finally, these PIs collected the cost data required to estimate the cost of producing and shipping fair trade beans to the United States.

In the United States, the PIs contacted various organizations that could provide third-party certification (Fair Trade Labeling Organization, FLO; Rainforest Alliance; International Marketing Organization, IMO) to determine their requirements for certification and associated costs. They then contacted various U.S. food retailers to determine interest in purchasing fair trade beans (and to determine the process for negotiating a supply contract).

ACHIEVEMENTS AND OUTPUTS

Angola

Analysis of a household survey in the high potential common bean production zones of the highlands indicated that about 70 percent of the farmers grew beans, of which 67 percent were sold. Farmers blamed the poor seed quality of locally purchased seeds for lower production and the limiting factor in market participation; they also identified high marketing costs as constricting the quantity sold.

Common bean market research indicated a preference for local over imported beans in Angola, yet smallholder farmers in the Planalto region lack marketing strategies to reach those markets and trade organization appears weak, implying high transaction costs. Interviews found that most farmers sell into local markets or to traders in the village, even when farmers associations exist. For market information, farmers listen to the new radio programs broadcasting prices but indicated they found different prices in the market.

As shown in Table 1, female-headed households tended to have lower average receipts, although no significant difference was observed in the average price received. Table 2 complements that information, demonstrating that women participate in the sales of beans in about one-third of the households, and more than half of the households when the head of household is a woman.

Table 1. Angolan Highlands bean sellers: Average receipts, costs, gross margins, and percentage sold per village type and gender of household head

	Gender of head		
Detail	**Male**	**Female**	**Total**
Receipts (Kw)	8,056	2,700	6,437
Price per kg sold (Kw/kg)	70	68	70
Total Costs (Kw)	1,521	813	1,307
Production costs per kg produced (Kw/kg)	8.7	12.3	9.8
Marketing costs per kg sold (Kw/kg)	3.1	1.7	2.7
Gross margins (Kw)	6,535	1,887	5,130
Total quantity sold (% of total production)	69	61	67
Number of sample observations	144	111	255

NOTES: Kw = Kwanzas. Costs include purchased inputs, hired labor and reported marketing costs. Variables are at the household level. Estimates weighted to reflect population. Source: Reyes 2011.

Table 2. Marketing strategies among farmers producing beans, per village type and gender of household head

	Gender of head		
Marketing strategies	**Male**	**Female**	**Total**
Person responsible of sales: (%)			
Head	73	57	68
Spouse	19	38	24
Both	7	0	5
Female is at least one of the responsible people	26	57	35
Responsible of sales looked for information of prices (%)*	70	69	70
If YES, main source of information: (%)**			
Spouse	5	5	5
Friend	43	52	46
Radio, Association, or IDA staff	0	0	0
Middlemen (traders)	50	31	45
Number of sample observations	148	112	260

* Binary variable (0 = No, 1 = Yes).
** Only if responsible of sales looked for information of prices.
Source: Reyes, 2011. Estimates weighted to reflect population.

For cowpeas, traders, almost all of whom are women, identified various transport problems. In the rainy season, some areas remain inaccessible, and transport costs remain high. Bruchid damage to grain was frequently found in the markets and limits the incentive to store for marketing in the off-season when prices are higher.

The research identified key areas for investment to improve the production and value chains for common beans and cowpeas in Angola:

1. Farmers considered the quality of locally available seed to be poor; greater availability of seed of improved varieties is needed.
2. The quality of the end grain is affected by the quality of the seeds planted. Common beans and cowpea harvests indicate mixing of varieties in the fields and in the bags for market, lowering the price received.
3. Farmers often do not know how to use price information when it's available.
4. Postharvest storage and controls of insect pests, especially bruchids, are of high importance to market a quality product at the best seasonal price.
5. Farmers selling common beans in the markets of Bailundo and Londimbuali received, on average, 52 percent of the final consumer price, with substantial margins going to wholesalers and to retailers (24 percent to each).

Mozambique

Researchers combined data sets in Mozambique to give a broad view of common bean and cowpea value chains. Common beans are grown by approximately 10 percent of households and were an important source of revenue for approximately 130,000 households in 2008. Mozambique market processes are relatively consistent across seasons, with high prices in the hungry season and low prices at harvest. Gungulo's (2013) research indicates that common bean farmers participate more in the markets when they have access to finance and market information as well as easy local access. However, women's access to these opportunities may be limited due to lower assets, lower education levels, and more limited access to finance information.

Cowpeas are grown by more than 455,000 Mozambican households and have traditionally been a dual purpose crop in that both the leaves and dry grain are consumed; dual purpose also applies to their uses—for home consumption as food security and market sales for income. In recent years, the market for cowpeas for export has increased. Linked to that fact are large-warehouse agents buying cowpeas for the export market.

As shown in Table 3, the volume of cowpea marketed is very low among farmers in the central region—less than 75 kgs on average. In the southern region, cowpea sales are higher for female-headed households than elsewhere in the country, indicating good potential for these households. Throughout the country, yield losses, low product prices, and lack of price information for cowpea farmers are key constraints to market participation.

Table 3. Mozambique: Average quantity of cowpeas harvested and marketed by year, gender and region

	Gender	Northern Region Kg	Central Region Kg	Southern Region Kg	Whole sample Kg
Average quantity harvested	Male	60.1	37.5	22.7	42.0
	Female	31.1	19.1	22.8	23.5
	t statistic	-5.70***	-5.04***	0.03	-7.29***
Average quantity marketed	Male	68.5	73.4	32.7	69.0
	Female	36.2	22.6	50.6	31.9
	t statistic	-2.88**	-3.72***	1.21	-4.69***

Note: t-statistics are from the test of equality of means, with the null hypothesis of the mean of male-headed households = mean of female-headed households. Means are weighted. Source: Gungulo, 2013.

There are key opportunities for improving the various markets for common beans and cowpeas in Mozambique. Given the concentration of large warehouse agents in cowpea trade, it could be possible to develop targeted actions to improve processing and storage as well as encourage quality in cowpea varietal choice. The lack of a functioning seed system in many zones constrains the responsiveness of both farmers and traders to market opportunities. A cellphone-based market information system remains an area for potential market efficiencies but relies on the SIMA data collection and distribution network remaining strong.

Honduras

More than 200 farmers from the Yojoa Lake, Yorito-Sulaco-Victoria, and Vallecillo regions have implemented organic fertilizers and pest control practices produced locally. More than 175 technical personnel and farmer leaders have received training at Zamorano or locally in producing and using organic fertilizers and plant extracts for pest control—and most can now elaborate their own organic fertilizer and pest control products. The use of different plant extracts as insect repellent and the application of foliar organic fertilizers based on earthworm humus, compost, and other organic sources on bean crops is becoming common.

Results from *Rhizobium* inoculant tests on farmer fields indicated the usefulness and potential adoption of this practice by small bean producers. With Pulse CRSP collaboration, more than 12 technicians from the national research institutes of Central American and Caribbean countries were trained on *Rhizobium* technology and inoculant production at Zamorano, and more than 5,000 farmers have tested the response to inoculants in their bean production.

Fair Trade

The steps required to produce and to export fair trade beans were far more complicated than initially anticipated.

Strong Farmer Interest. Farmers in the association expressed a strong interest in participating in the project. In addition, a local NGO, Program for Rural Reconstruction, agreed to serve as the project's facilitator.

Fair Trade Certification. Initially, we planned to seek certification from the Fair Trade Labeling Organization (FLO); however, before FLO would certify a farmer association as meeting its requirements, FLO had to have previously established standards for the crop to be certified and have set a fair trade price. Since no standards or fair trade price had been previously established, we contacted the International Marketing Association (IMO), which certifies farmer associations rather than a specific crop or crops. The IMO agreed to provide third-party certification, subsequent to the Association completing a 50-plus page application (i.e., provide information regarding the Association's membership, governance, etc.), passing an IMO audit visit to verify information in the application, and paying an audit fee of $2,700.

U.S. Retailer. The bulk commodity buyers at Whole Foods Market (WFM) were very interested in purchasing 20 mt of small red beans for delivery in January 2012, if the IMO certified that the Association met its standards and the farmers agreed to Whole Foods Market's price.

Table 4. Estimated Supply Chain Costs (US$/lb), Honduras to the US

Cost Item/Service	Cost/lb
IMO Certification	$0.09
Farmgate Price	$0.60
Fair Trade Premium (10%)	$0.06
Marketing/Processing	$0.07
Shipping to Houston	$0.05
Total Cost to WFM	$0.87

The Supply Chain. Through visits to Honduran government officials, traders, wholesalers, brokers, shippers, and U.S.-based food importers, the PIs documented the supply chain and the associated costs (Table 4) for moving the beans from the farm gate to the U.S. Port of Houston (i.e., fair trade certification, farm gate price, cleaning, fair trade premium of 10 percent, bagging and packing at the Association level, brokerage costs, fumigation, bringing a container to the village and transporting it to the export port, Honduran customs and phytosanitary paperwork, sea transport to Houston, U.S. customs brokerage fees, and transporting to Whole Foods Market's warehouse).

Sales Price. In early 2011, the members of the association agreed to sell 20 mt of beans to Whole Foods Market at a $U.S. 0.60/lb; however, local bean prices rose to unprecedented levels during the year, and farmers expected the price to remain at this level throughout the year. In May, the farmers asked for a price of $U.S. 0.90/lb for beans to be delivered in January 2012, and the PI contacted the bulk commodity buyers at Whole Foods Market. WFM offered $U.S. 0.75, but was unable to pay $U.S. 0.90/lb. Consequently, negotiations were terminated; however, WFM agreed to reopen negotiations the following year, if the association reduced its requested price.

POTENTIAL DEVELOPMENTAL OUTCOMES AND BENEFITS TO PULSE VALUE CHAIN(S)

Angola

The identification of leverage points along the value chain has contributed to discussions about allocation of resources for future public sector investments for pulse value chain development. An agricultural market information system may yet be developed through the efforts of the Pulse CRSP-trained graduate, Estevao Chaves. For cowpeas, this research coupled with diagnosis by the UCR team may result in future investments in postharvest handling to reduce insect pests to cowpeas for marketing, thus increasing the market value and returns to trade and storage. More work is still needed to link urban demand in Luanda to varieties and production quantities in the highlands.

Mozambique

Addressing constraints related to common bean seed and quality would increase their marketability and enhance the market for export, improving the livelihoods of common bean producers. In turn, these potential export markets would further encourage formal sector traders to work with common beans. Postharvest issues that were identified can be resolved with existing methods, future work with the private sector, and producers.

The research identified key wholesale traders of cowpeas; thus, improvements in the cowpea value chain can be achieved through this small set of traders, especially for postharvest issues and possibly for seed system development.

Honduras

The EAP/Zamorano bean research program continues to support the testing and dissemination of sustainable bean production technologies and the training of technical personnel and farmer leaders on sustainable bean production practices. In addition, cultivars that combine better disease resistance with tolerance to low fertility developed in collaboration with other Pulse CRSP projects (UPR-1 and PSU-1) have been made available to farmers in the region.

More than 50 percent of the farmers involved in the project have increased bean productivity, more than 20 percent through improved cultivars and management practices. Training on organic production practices and on *Rhizobium* technology and inoculant production continues to be provided.

Technical capacity has been developed by training technical personnel from various Central American and Caribbean countries. Laboratories in Guatemala, Nicaragua, and Haiti are being implemented and initial production of inoculants has already been started in Guatemala and Haiti. In the meantime, the laboratories from Zamorano and UPR are providing the inoculant needed for the regional testing and dissemination on additional farmers' fields.

Fair Trade

While fair trade certification represents a potential opportunity for farmers to receive a premium price for their beans, several obstacles must be overcome to take advantage of this opportunity, including farmer willingness to set the purchase price six months prior to delivery. Second, the process for obtaining fair trade certification is extremely complex, and farmers require technical assistance to gain certification. Third, because obtaining fair trade certification is expensive, the market is limited to upscale U.S. food retailers. Fourth, several risks are associated with selling to an export market, including the possibility that some associated delivery costs may rise before the product is shipped and reduce the profit farmers receive. Finally, farmers hoping to export to U.S. markets must meet the strict phytosanitary standards of U.S. Customs/APHIS (e.g., zero tolerance for bruchids) and the retail buyer's standards.

CONTRIBUTIONS TO INSTITUTIONAL CAPACITY BUILDING

Angola

Contributions include an M.S.-degree student trained: Estevao Chaves, 2011, Federal University of Vicosa (Brazil); value chain training for UAN students and faculty (2008); data entry and processing (2009); collection and analysis of market prices (2012); partial budgeting for UJES students, faculty, and staff from IIA and other agencies (2012); and additional presentations and in-service trainings: Agricultural policy and prices (2010) and a class session for 35 UAN (UJES) students and faculty.

Mozambique

Contributions include an M.S.-degree student trained: Ana Lidia Gungulo, 2013, University of Pretoria (South Africa); value chain training (2009); STATA analysis of time series data training (2010); introductory training on investment and cost benefit analysis (2012); and market efficiency training (2012).

A vehicle was purchased in Mozambique for market and other research in 2012 and will continue to transport legume researchers in key production and marketing zones. Camtasia Software and video recording hardware was purchased for both UJES (Angola) and IIAM (Mozambique) to develop training/presentations with integrated systems of video, audio, and MS Powerpoint.

Honduras

The project provided training to technical personnel and farmer leaders in organic bean productions, including technologies to sustain fertility and control pests and diseases. In addition, technical personnel from various countries were trained to conduct research in *Rhizobium* technology and to produce inoculants.

KEY PUBLICATIONS

Adolfo Dala Catuti. 2011. *Identificação de Oportunidades e Constrangimentos na Produção e Comercialização da Cultura de Feijão no Municipio do Bailundo Província do Huambo.* Thesis for Licenciatura, University Jose Eduardo dos Santos, Chianga, Huambo, Angola.

Txocanaie, R., A. Catuti, D. K. Kiala, and C. Donovan. 2012. Market Chain and Key Actors for Common Beans in Huambo, Angola. Poster presented at the Global Pulse Researchers Meeting in Kigali, Rwanda, 13–17 February 2012.

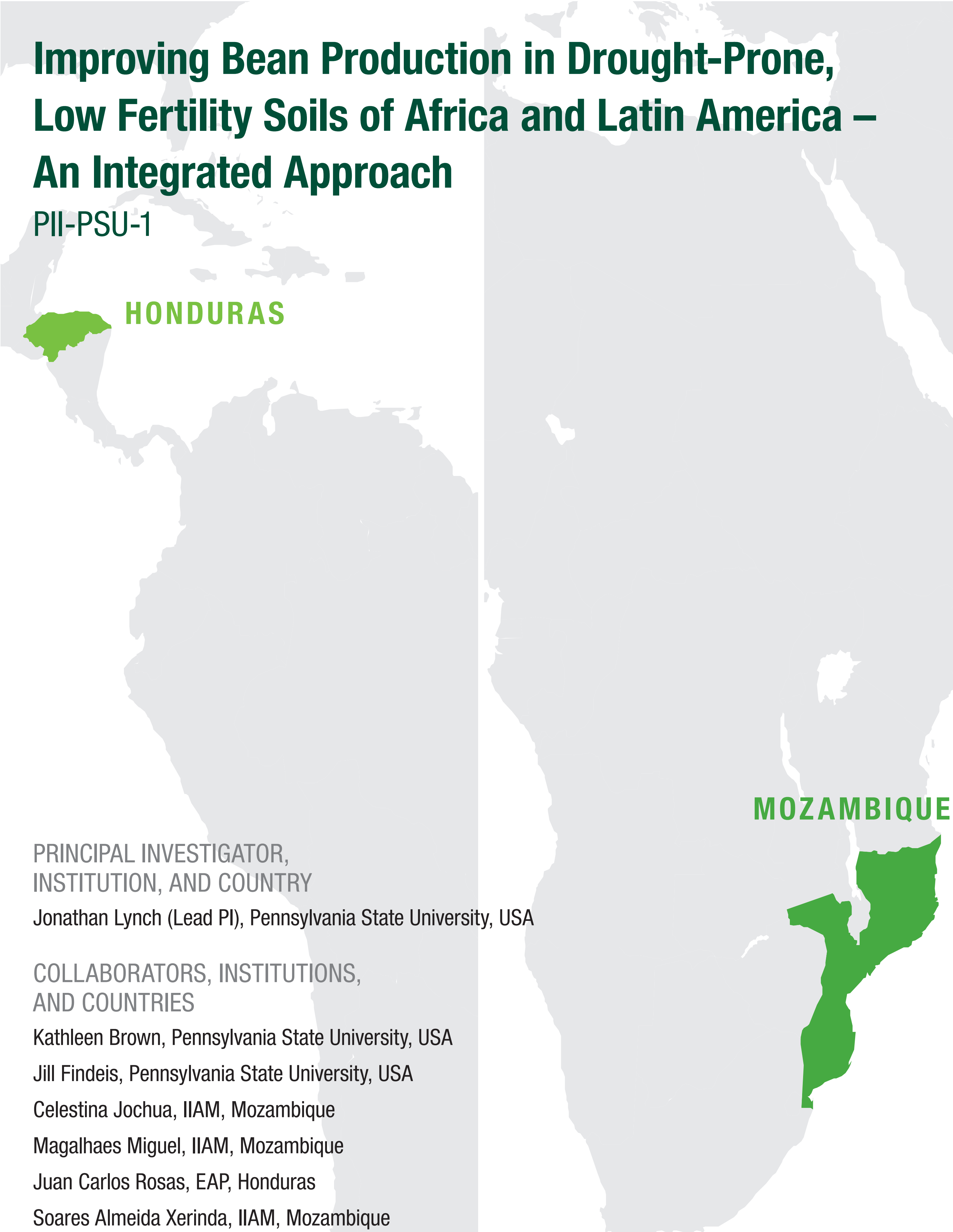
Reyes, Byron. 2011. *The Economic Impact of Improved Technology and Determinants on Market Participation: Evidence from Latin America and Angola*. Ph.D. dissertation. East Lansing: Michigan State University.

Bernsten, Richard H., Juan Carlos Rosas, and Byron Reyes. 2012. Exporting Fair Trade Beans from Honduras to a U.S. Market. Poster presented at the Global Pulse Researchers Meeting in Kigali, Rwanda, 13–17 February 2012.

Cachomba, Isabel and Cynthia Donovan. 2012. Value Chain Analysis of Common Beans in Mozambique. Poster presented at the Global Pulse Researchers Meeting in Kigali, Rwanda, 13–17 February 2012.

Improving Bean Production in Drought-Prone, Low Fertility Soils of Africa and Latin America – An Integrated Approach

PII-PSU-1



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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

Introgression of root traits into elite lines has generated new bean lines with substantially greater stress tolerance in Mozambique.

Drought and low soil fertility are primary, pervasive constraints to bean production in the low-input smallholder farming characteristic of Central America and sub-Saharan Africa. The goal of this project was to improve bean production by developing new bean cultivars with root traits improving growth and yield in stressful soil environments. The project was highly successful. New root traits and genetic strategies were identified that improve bean growth in stressful soils, including basal root whorl number, root hair length and density, and genetic multilines.

Variation for these traits among bean genotypes was related to substantial yield gains (in some cases 200–300 percent) under drought and low phosphorus stress in the field. Selection for beneficial root traits supported the release of multiple new bean lines with greater tolerance to drought and low soil fertility in Central America. Introgression of root traits into elite lines has generated new bean lines with substantially greater stress tolerance in Mozambique. New bean lines with root traits enhancing phosphorus acquisition reduce soil erosion, increase water utilization, substantially improve biological nitrogen fixation, perform better in maize intercrops, and are more responsive to fertility inputs and mulching than conventional lines. Socioeconomic analysis identified constraints and opportunities to the adoption and dissemination of new bean lines.

PROBLEM STATEMENT AND RESEARCH APPROACH

Drought and low soil fertility are principal, pervasive constraints to bean production in Latin America and Africa. Recent developments in our understanding of root biology make it possible to breed crops with greater nutrient efficiency and drought tolerance. Such crops will improve productivity, enhance economic returns to fertility inputs, and may enhance overall soil fertility and system sustainability, without requiring additional inputs. The overall goal of this project was to realize the promise of this opportunity to substantially improve bean production in Africa and Latin America.

Beans vary substantially in drought tolerance, due primarily to variation in root depth and access to soil water, earliness (drought escape), and secondarily to seed filling capacity. Drought tolerance has been identified in several races of common bean. Utilization of specific traits in drought breeding through direct phenotypic evaluation or genetic markers (e.g. QTL) would be useful.

Phosphorus limitation is the most important nutrient constraint to bean production, followed by the acid soil complex of excess Al, excess Mn, and low base supply. Fertilizer use is negligible in many developing countries, which generally have the poorest soils. What is needed is integrated nutrient management, consisting of judicious use of fertility inputs as available, management practices to conserve and enhance soil fertility, and adapted germplasm capable of superior growth and yield in low fertility soil.

We have shown substantial variation in bean P efficiency in Latin America. Analysis of the CIAT germplasm collection identified several sources with outstanding P efficiency. Studies with these genotypes identified a number of distinct root traits that contribute to P acquisition through topsoil foraging, including root hair length and density, adventitious rooting, basal root whorl number, basal root shallowness, and traits that reduce the metabolic costs of soil exploration such as root etiolation and root cortical aerenchyma. Genetic variation for these traits is associated with 250–600 percent variation in growth and P uptake among related genotypes in field studies.

The introduction of bean genotypes with superior root systems may enhance the utilization of rock P, thereby improving P availability and N availability in maize/bean systems. Similarly, bean genotypes with deeper root systems may be synergistic with soil management techniques to conserve residual moisture.

We also need a better understanding of socioeconomic factors determining adoption of stress tolerant bean germplasm and the likely effects such adoption may have on household income and nutrition.

ACHIEVEMENTS AND OUTPUTS

To develop bean genotypes with improved tolerance to drought and low P

Several specific root traits that enhance bean productivity under drought and low fertility stress have been identified. In this project, the overall goal for this knowledge is to improve bean production in Africa and Latin America through genetic improvement. Activities include identification of root traits enhancing stress tolerance, development of screening protocols for these traits, use of these protocols to identify sources of tolerance traits, introgression of root traits into elite lines in Africa and Latin America, and evaluation and development of low P/drought tolerant varieties for farmers using participatory selection and breeding.

The project was successful in identifying new traits and genetic strategies enhancing tolerance to stressful soils, including basal root whorl number, root cortical aerenchyma, synergism between root hair length and basal root growth angle, root dimorphism, root architectural multilines, and polycultures.

Utility of Basal Root Whorl Number (BRWN) for water and P acquisition

We discovered that a dominant root class in the bean root system, basal roots, appears in distinct positions or whorls that vary among genotypes. We hypothesized that genotypes with greater BRWN would have greater tolerance to drought and low P. Results from field studies in Mozambique, South Africa, and Pennsylvania support this hypothesis. Genetic analysis of this trait suggests that the potential for deployment of these traits in bean breeding programs is very good. The trait is extremely easy to visually phenotype in laboratory grown seedlings four days after imbibition. Selection for greater BRWN is currently being using in breeding programs in Mozambique and Honduras.

Utility of root cortical aerenchyma (RCA) for nutrient acquisition

The formation of root cortical aerenchyma reduces root respiration and nutrient content by converting living tissue to air volume. It was hypothesized that RCA increases soil resource acquisition by reducing the metabolic and phosphorus cost of soil exploration. Sensitivity analyses for the effects of RCA on the initial 40 days of growth in common bean were conducted in soils with varying degrees of phosphorus availability. The model showed that RCA may increase the growth of plants faced with suboptimal phosphorus availability up to 14 percent for bean after 40 days of growth. Maximum increases were obtained at low phosphorus availability (3 mM). Larger benefits may be expected for mature plants. The results support the hypothesis.

Root phene synergism for P acquisition

Root hair length and density (RHL/D) increase phosphorus acquisition by expanding the soil volume subject to phosphorus depletion through diffusion.

Shallow basal root growth angle (BRGA) increases phosphorus acquisition by enhancing topsoil foraging, since in most soils phosphorus is concentrated in the topsoil. Root hair length and density (RHL/D) increase phosphorus acquisition by expanding the soil volume subject to phosphorus depletion through diffusion. We hypothesized that shallow BRGA and large RHL/D are synergetic for phosphorus acquisition, meaning their combined effect is greater than the sum of their individual effects. Research revealed substantial synergism between BRGA and RHL/D. Long root hairs increased shoot biomass under phosphorus stress by 89.3 percent while shallow roots increased shoot biomass by 57.7 percent. Genotypes with both long root hairs and shallow roots had 298 percent greater biomass accumulation than short-haired, deep-rooted phenotypes. The utility of shallow basal roots and long root hairs for phosphorus acquisition in combination is therefore twice as large as their additive effects.

Root architectural multilines

The combined drought and low phosphorus situation is complex because shallow soil generally has greater P availability and deep soil has more plant available water. A novel approach is to pair genotypes with contrasting root architectures but identical agronomic characteristics (multilines), so that the field of plants performs well under combined drought and low P stress and has greater yield stability and greater resilience to severe drought events. We found a consistent benefit of bean architectural multilines compared to the average yield of the component lines under stressful conditions in trials in Honduras. We found consistent results in South Africa.

Bean polycultures have greater nutrient acquisition than bean monocultures

Since ancient times in the Americas, maize, bean, and squash have been grown together in a polyculture known as the *three sisters*. This polyculture and its maize/bean intercropping variant have been shown to have greater yield over monocultures on a land equivalent basis. Our research showed how below-ground niche complementarity may contribute to this yield advantage. Maize acquired the greatest fraction of nutrients from the topsoil by placing more roots in the topsoil than the subsoil. Common bean explored the vertical soil profile more equally, and squash's root placement depended mostly on phosphorus application. These differences in root placement may have reduced interspecies root competition and increased total soil exploration, with consequent positive effects on plant growth and yield.

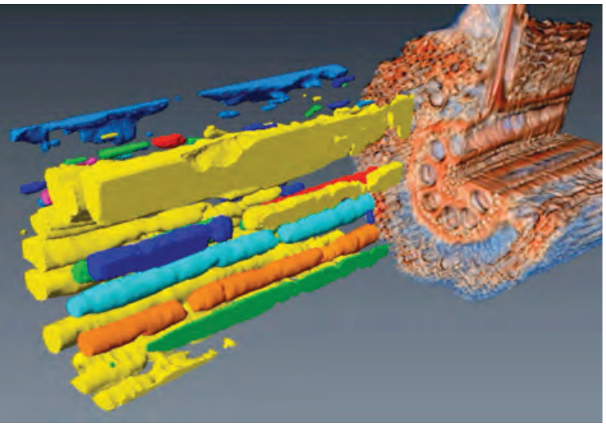
Bean root systems excavated from the field in Honduras, showing genetic variation for basal root growth angle.

Development of novel high-throughput screening platforms

A significant challenge to the deployment of root traits in bean breeding programs is the difficulty of rapidly evaluating root traits of field-grown plants. In this project we developed two novel screening platforms: *shovelomics* for rapid screening of root architectural traits in the field and *laser ablation tomography* for rapid evaluation of anatomical traits.

Diversity of root traits of common bean from Andean and Mesoamerican gene pools

To assess the diversity of root traits in bean germplasm, 165 accessions from the bean core collection from CIAT were planted in the laboratory and field in Pennsylvania in 2010. Fifteen root traits were evaluated from each root crown: adventitious root number, length, branching and diameter, basal root number, length, branching and diameter, basal root growth angle, primary root length, branching and diameter, basal root whorl number, number of nodules, and root rot infection. Substantial phenotypic variation in root traits among genotypes was found in adventitious, basal, and primary root traits. Variation among genotypes within gene pools and genotypes within country of origin were significant for all 15 root traits. Useful root traits for breeding for edaphic stresses were identified in both Andean and Mesoamerican gene pools. Breeding for multiple root phenes could enhance acquisition of multiple soil resources, particularly in developing countries.



Reconstructed root anatomical features created from images collected using laser ablation tomography.

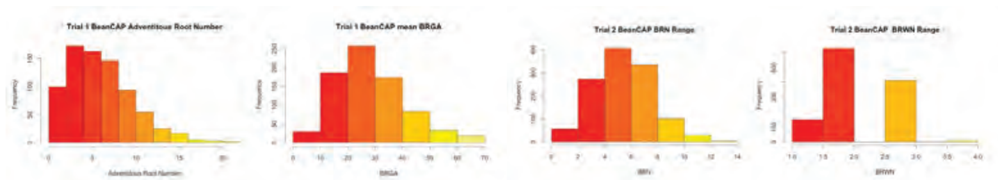
Phenotyping bean diversity panels

Several collections have been evaluated to quantify variation for root architectural traits, identify sources of beneficial traits, and understand the genetic control of root traits. These data will be compiled and analyzed to identify QTL related to root traits and establish coefficients of relatedness to promote an understanding of how root traits are inherited.

We found substantial variation in adventitious root number and length, basal root number and length, and basal root whorl number in a reference collection assembled by CIAT representing global genetic diversity. Most Mesoamerican genotypes had two basal root whorls with seven to eight basal roots, and these Mesoamerican genotypes had deeper roots that confer tolerance to drought stress. Andean genotypes had two to three basal root whorls, with several basal roots (seven to 11), and shallow basal roots compared to genotypes from Mesoamerican origin.

Having identified useful root traits for improving adaptation to stressful soils and having identified sources of trait variation in bean germplasm, the third and critical step is to deploy these traits in bean breeding programs: that of Dr. Juan Carlos Rosas in Honduras focusing on small red and black-seeded lines of the Mesoamerican gene pool for Central America and the Caribbean, and that of Celestina Jochua in Mozambique focusing on Andean types important in Southeastern Africa. Breeding progress has been realized in both programs. Dr. Rosas is employing root hair and root architectural traits as part of an inbred backcross and recurrent selection breeding program for drought and low soil fertility in combination with disease resistance and other traits. Celestina Jochua is selecting lines with greater BRWN, shallow root growth angles, and introgressing root hair traits into elite backgrounds.

Basal root phenotyping of a North American bean diversity panel. BRGA: basal root growth angle; BRN: basal root number; BRWN: basal root whorl number.



Breeding Mesoamerican bean lines with greater tolerance to drought and low P availability at Zamorano, Honduras

Significant progress has been realized at Zamorano in breeding more stress tolerant bean lines with superior root traits. The 83 percent increase in yield under stress of the best IBC lines compared with their parents indicates the magnitude of the potential benefits from selection for root traits. Analysis of the root traits of stress tolerant lines in the field has confirmed the value of specific traits, including adventitious rooting under nutrient and drought stress.

A strong positive correlation between yield under low P stress and root hair length was observed in 14 bean lines.

In collaboration with the UPR/Beaver Project, landrace cultivars and elite breeding lines have been used to develop improved small red and black bean cultivars with better adaptation to limiting soil fertility and rainfall conditions at Zamorano. Several advanced lines have been developed by inbred backcross and triple crosses using improved cultivars and breeding lines as donor parents. The line IBC 301-204, one of the most promising from this group, was released in 2012 as a cultivar for commercial production in the Atlantic tropical humid region of Nicaragua. IBC 301-204 showed greater number of adventitious roots, shoot biomass, and seed yield than other promising lines and check cultivars. The drought tolerant line SEN 96 from CIAT also showed superiority in number of adventitious roots, shoot biomass, and seed yield. Several other small red and black breeding lines are in advanced testing in Honduras and other Central American countries. Lines developed under the project are included in regional trials distributed by Zamorano as part of the drought and heat tolerant trial for climatic change.

Figure 9. Demonstration plots in farmer's field association, Chokwe, 2012.

Figure 10. Farmers evaluating common bean lines, at Chokwe Research Station, during the field day.

During the course of this project, Dr. Rosas released five small red seeded cultivars tolerant to drought and low soil fertility and having resistance to BGMYV (bean golden mosaic yellow virus) and BCMV (bean common mosaic virus) in Nicaragua (2010) and El Salvador and Honduras (2012); two small red seeded cultivars with drought tolerance and resistance to BGYMV and BCMV as well as greater than 10 percent increased seed Fe content in Nicaragua (2010), El Salvador (2011), and Honduras (2012); and four small black seeded cultivars tolerant to drought and low soil fertility with resistance to BGMYV and BCMV in Haiti (2009–2011) and Guatemala (2010).

Breeding Andean bean lines with greater tolerance to drought and low P availability
The breeding program of Celestina Jochua at IIAM has made good progress in identifying lines with superior root traits and has focused on developing elite lines adapted to regional agronomic and market preferences with long, dense root hairs, which are useful for P acquisition. In deploying for this trait, we characterized diversity for root hair traits in two bean populations and studied the mechanisms of inheritance of root hair traits in common bean. Results indicate that root hair traits vary genetically and can be targeted in breeding programs to improve bean cultivars.

To evaluate the possibility of introgressing root hair and other promising traits in Mesoamerican bean lines, five single crosses were performed using parents with root traits adapted to low P and drought, and generations were advanced to F6. A strong positive correlation between yield under low P stress and root hair length was observed in 14 bean lines in 2012. These results show that introgression of root hair traits in Mesoamerican bean lines can substantially increase yield (in this case, doubling yields) in low P soils.

We have identified several root architectural traits that improve rooting depth and therefore yield under drought, mainly steep basal root growth angles; lines with steep root angles have up to 80 percent better yield under drought than shallow-rooted lines.

To develop integrated crop management systems for stress tolerant bean genotypes

Our project combines the development of new bean lines with greater stress tolerance with agroecological research to determine what crop management strategies are appropriate with the new lines and to understand the impacts of the new lines on the productivity and sustainability of bean cropping systems. Our results show important benefits of new, P-efficient bean lines for ecosystem processes, including reduced soil erosion, greater water utilization, and greater biological N fixation. We found that the new lines cause only marginal yield reductions of maize when grown as maize/bean intercrops, and that they greatly benefit from mulching.

P-efficient bean lines reduce erosion and enhance water utilization

Much common bean production in Latin America and sub-Saharan Africa is done on steep, erosion-prone slopes with low soil fertility. A study in a low phosphorus soil in Mozambique evaluated the effect of shallow-rooted bean genotypes on alleviation of water erosion, including reduction in runoff water, sediment, and P in runoff water. Results showed that shallow-rooted genotypes had 81.2 percent more roots in the surface 15 cm soil than deep-rooted genotypes and consistently less runoff water volume, sediment, and dissolved P than deep-rooted genotypes.

P-efficient bean lines have greater biological N fixation

The hypothesis that P-efficient common bean genotypes have better nodulation and better N2 fixation than conventional genotypes was tested. P-efficient genotypes had significantly greater nodulation efficacy than P-inefficient genotypes. Under low P, inoculation increased the nodule number of P-efficient genotypes by 34 to 71 percent. For P-inefficient genotypes, inoculation increased nodule number by 20 to 46 percent. Nodule activity of P-efficient genotypes was between 50.6 percent and 92.5 percent—at least 30 percent greater than for P-inefficient genotypes.

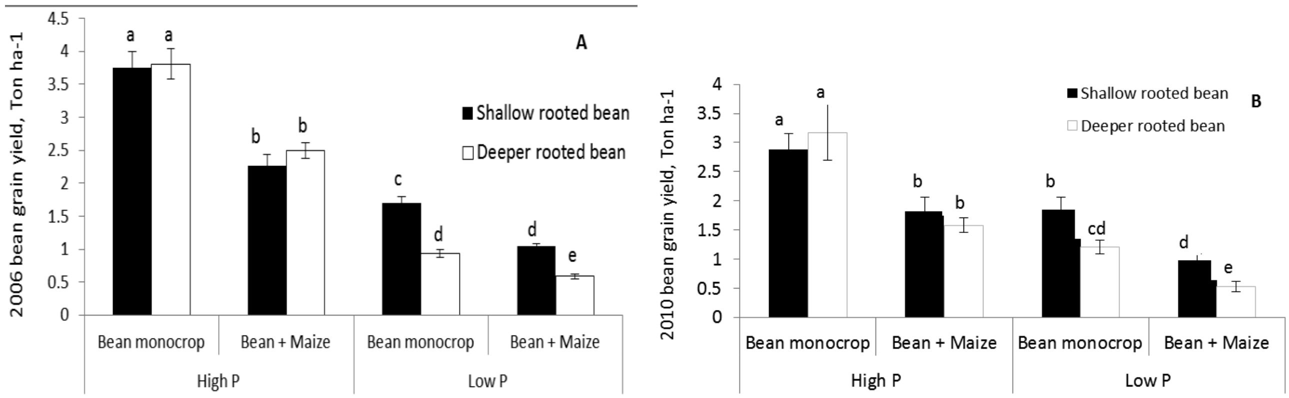


Figure 11. Grain yield of common bean genotypes differing in root shallowness monoculture and associated with maize under low and high phosphorus (P) conditions in Pennsylvania.

P-efficient bean lines perform better in maize intercrops

We assessed the performance of new bean lines with superior root traits in a maize–bean polyculture. When intercropped with maize, under low P, the shallow-rooted bean yield was 1.04 ton ha-1—43.3 percent greater than the yield of the deep-rooted phenotypes.

Socioeconomics

The objective of the socioeconomic research was to identify constraints and opportunities to the adoption and dissemination of new bean lines and to understand their potential impact on household income and nutrition. The benchmark survey indicated that a majority of respondents wanted security—both social and market— before adoption, that is they would not want to be first adopters but would prefer to see others successfully grow a new cultivar first. The majority of respondents also reported that they would have to be shown how to grow it before they would try it.

ACHIEVEMENTS AND OUTPUTS

An important achievement of the project was the development of eight village sites for long-term assessment of outcomes based on application of social network analysis (SNA).

Bean sales are an important source of income for a large majority of farms in the selected villages in Mozambique's bean-growing regions, particularly for households in Niassa and Zambezia provinces; most Niassa households did not consider bean profitability a problem, while those in Zambezia and Tete provinces, where sales were significantly lower, reported profitability as a problem, emphasizing the need for market development. (At the same time, it should be stressed that beans were important for household consumption in these two regions, with sufficient food reported as a very serious issue.)

Three out of four households in Tete and Zambezia Provinces reported that they considered not enough good bean seed available locally to be a large problem. In Niassa Province, roughly 65 percent of households didn't find having enough bean seed a problem. Study results provide evidence that formal channels such as seed stores, extension, NGOs, or farmers' organizations are not driving the (rapid) spread of improved seed varieties, despite interest by farmers.

Mozambican households reported strong interest (>70 percent) in producing soybeans, if guaranteed a buyer. This was also the case for black beans in the three provinces. Over the course of the project, growth in local engagement in soybean production for poultry was a major development, suggesting a strong potential for P-efficient soybean varieties.

An important achievement of the project was the development of eight village sites for long-term assessment of outcomes based on application of social network analysis (SNA).

POTENTIAL DEVELOPMENTAL OUTCOMES AND BENEFITS TO PULSE VALUE CHAIN(S)

This project has identified root traits that substantially improve bean yields in stressful soils characteristic of smallholder farmers, has deployed these traits in leading bean breeding programs in Central America and Southeastern Africa, has identified positive effects of the new bean lines for sustainable intensification of bean production systems, and has identified constraints and opportunities to the adoption and dissemination of new bean lines in Mozambique.

The success of Dr. Rosas and Celestina Jochua in deploying specific root traits for bean improvement is an important model that is informing other breeding efforts in the region.

The success in deploying specific root traits for bean improvement is an important model that is informing other breeding efforts in the region.

Socioeconomic results emphasize the need for greatly improving access to new seed as a strategy to improve food security and relieve hunger. Seed sharing has the disadvantage of slow diffusion. Fortunately, in Mozambique, the problem of seed release delays has recently been dealt with via the release of 11 new cultivars (including common bean and soybean) and issuance of the *Provisory Regulation of Seed Release, Ministry of Agriculture, Ministerial Diploma 18/2012*, which allows for additional flexibility in cultivar testing and release. The urgency of providing African children with sufficient protein and micronutrients essential for development before and after birth will substantially increase under all population projections. Solving the seed access problem represents a major challenge in the East Africa region and its solution will undoubtedly serve to reduce binding constraints to higher bean yields in areas that have the potential for higher productivity in Mozambique and in the East Africa region.

CONTRIBUTIONS TO INSTITUTIONAL CAPACITY BUILDING

A significant outcome from this project is the development of an interdisciplinary team at IIAM comprised of Dr. Magalhaes Miguel (physiology), Celestina Jochua (breeding), Soares Xerinda and Samuel Camilo (agronomy), and Maria da Luz Quinhentos (socioeconomics), who are effectively working together to improve the bean value chain in Mozambique. In addition, bean breeder Virginia Chesale defended her MSc thesis and returned to her post in Malawi.

KEY PUBLICATIONS

Basu P, Y-J Zhang, JP Lynch, KM Brown. 2007. Ethylene modulates genetic, positional, and nutritional regulation of root plagiogravitropism. *Functional Plant Biology* 34:41–51.

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Postma, JA and JP Lynch. 2012. Complementarity in root architecture for nutrient uptake in ancient maize/bean and maize/bean/squash polycultures. *Annals of Botany* 110:521–534.

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

PII-UCR-1

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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

The primary objectives were 1. to develop improved, pest resistant, and drought tolerant cowpea varieties for target regions in sub-Saharan Africa and the United States using modern plant breeding tools, 2. to strengthen cowpea seed production and delivery systems in Angola, Burkina Faso, and Senegal to ensure delivery of improved varieties, and 3. to develop a cowpea breeding program in Angola and strengthen existing breeding programs in Senegal and Burkina Faso through targeted training and capacity building.

Elite novel, dry grain green and all-white blackeyes were evaluated in multiyear, multilocation, on-station trials for grain quality, yield, and disease and insect resistance.

In California, black-eyed cowpea CB50—with larger, brighter white seed and sold as a premium export class—was released and has gone into production. Elite novel, dry grain green and all-white blackeyes were evaluated in multiyear, multilocation, on-station trials for grain quality, yield, and disease and insect resistance; data was collected to support the best one for release. In Burkina Faso, six varieties were released, including large white-grain types and *Melakh*, bred by the Pulse CRSP in Senegal and found to be an excellent variety in Burkina Faso. In Senegal, line *ISRA-2065*, with thrips and aphid resistance, was released in 2011 as *Pakau* and about 2,000 kg of foundation seed was produced for certified seed development for production farmers. Advanced multilocation yield trials over five seasons led to three new lines proposed for release in Senegal based on grain quality, yield, and disease and insect resistance. In Burkina Faso and Senegal, new breeding populations combining high yield, grain quality, and abiotic and biotic stress resistance traits were developed.

The seed production and delivery systems objective focused on breeder, foundation, and certified seed production of 11 and three new and preferred varieties in Burkina Faso and Senegal, respectively. Seed supply was ramped up over project years and coupled with foundation and certified seed producer training for farmers' organizations in the main cowpea regions of both countries. In Angola, yield and grain evaluation of local and Pulse CRSP cowpea varieties provided an initial step toward better yielding and more uniform varieties in the production system. Capacity building was achieved through training of seven graduate students and two postdoctoral fellows from five African countries and the United States.

PROBLEM STATEMENT AND RESEARCH APPROACH

Low agricultural productivity is central to rural and urban poverty in Africa. Cowpea yields in West Africa average 240 kg/ha; potential yields are five to 10 times greater. Drought, poor soil fertility, insect pests, and diseases are major constraints. The primary project focus is to increase productivity of African and U.S. cowpea producers through improved varieties that possess resistance or tolerance to the major abiotic and biotic stresses impacting production. Increased production should then lead to expansion of grower marketing opportunities. Breeding activities are coupled with ensuring adequate seed supply of improved cowpea varieties and providing training and capacity building in modern cowpea breeding to African researchers.

Peronospora manshurica

New cowpea varieties must have features desired by consumers and farmers, including grain appearance and desirable cooking and processing qualities for specific products. Large white grains with rough seed coat are preferred throughout West Africa and can be marketed over a wide area. They are also amenable to direct dry milling for use in value-added foods (akara, moin-moin) and prototype value-added products. There is also considerable demand for large rough-brown seed type, especially in urban centers in Nigeria, but current varieties are susceptible to pests and diseases.

Cowpea breeding by the CRSP, African NARS, and IITA has led to improved cowpea varieties now available or nearing release; however, only about five percent of the cowpea area in Africa is planted to improved varieties. Effective models for production and dissemination of improved cowpea seed have evolved in Burkina Faso and Senegal based on collectives, for-profit seed cooperatives, and for-profit individuals or groups; limited scope reflects insufficient quantities of breeder and foundation seed. We support increased production of breeder and foundation seed to ensure adequate certified seed supply and distribution to cowpea farmers.

ACHIEVEMENTS AND OUTPUTS

Development and release of new cowpea cultivars

Development and release of new varieties has been a major goal of the project under three established breeding programs in Burkina Faso, Senegal, and the United States, and via initial interactions with the Angola NARS cowpea program to assess their needs and current germplasm and local varieties. These breeding activities form a continuum of cowpea populations and lines at different stages of selection and advancement.

Senegal

The breeding line *ISRA-2065* was released in 2011 as variety *Pakau*. It was developed from a cross between the high-yielding Pulse CRSP cultivar *Mouride* and aphid and thrips resistant local landrace accession *58-77*, with the objective of developing a cultivar with the yield and stability of Mouride but with resistance to aphids and thrips. Pakau is an early variety (60 days from planting to maturity) and has the same desirable grain quality as Mouride. Combined with the variety release, more than 2,000 kg of foundation seed was produced in 2011–2012. In addition to Pakau, three other elite breeding lines are being proposed for release as varieties in Senegal based on excellent grain quality, yield, and disease and insect resistance.

Part of the money obtained by selling the foundation seed produced in 2011 was used to support 2012 seed production activities to establish a self-sustaining plant seed production and delivery system.

From the new crosses made at ISRA, progeny selection and advancement were made to develop varieties with medium to late maturity to cope with the changing cropping season length in the northern zones and with the growing interest in cowpea in the south and eastern areas. These materials included thrips resistance and good grain size and color qualities.

In new breeding streams, biparental crosses between highly drought tolerant lines were made and advanced at UCR. Individuals from the most drought tolerant lines will be used for crossing to the improved lines to produce drought tolerant elite varieties.

Burkina Faso

From multiple years of field testing, six varieties have been released from the Pulse CRSP breeding program (I*T98K-205-8l, Melakh, KVx421-2J, KVX442-3-25, KVx771-10* and *KVx735-33-2*), which yield an average of 1,250 kg/ha. In 2012, up to 8000 kg of certified seed per variety of the new varieties was produced and at least 40 tons of foundation seed to ramp up adoption and production of the new releases. Part of the money obtained by selling the foundation seed produced in 2011 was used to support 2012 seed production activities to establish a self-sustaining plant seed production and delivery system.

Angola

Evaluations were made of the current seed system and the available cowpea varieties and landraces. Local varieties were assessed together with the Pulse CRSP minicore collection, which carried a broad range of desirable traits, especially insect, disease, and nematode resistance and drought and heat tolerance, plus different maturity classes and plant architectures. Attempts were made to select the most desirable grain types from market collections and initiate selection for true type for testing and release as new varieties.

United States

A new black-eyed cowpea cultivar designated *CB50* with improved grain quality and more effective resistance to Fusarium wilt and root-knot nematodes was released in 2009. Breeder and foundation

Development of persistent-green black-eyed cowpeas may open new marketing opportunities for fresh-shell and rehydrated frozen products.

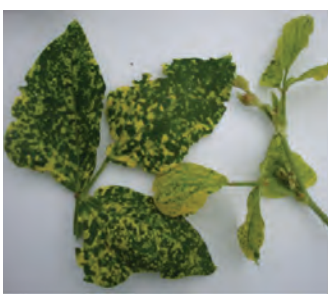
seed of the new variety were produced and large amounts of certified seed are now available to production growers. As part of the continued development and testing of new elite black-eyed lines, four of nine advanced lines derived from crosses between CB50, CB46, and other elite black-eyed types and selected from 2010 and 2011 trials have been selected for seed increase and larger scale replicated testing.

Development of persistent-green black-eyed cowpeas may open new marketing opportunities for fresh-shell and rehydrated frozen products. Upon soaking in water, their grains resemble fresh-shelled immature black-eyed grains that have high value as a vegetable crop in the southeastern United States and, potentially, other regions. Over the last three years, 12 new advanced dry-green breeding lines were screened and the seven best yielding/grain quality types were field tested. Seed increase was made of the three highest performing lines, which will be yield tested to determine the best candidate for release.

We have developed high-yielding, all-white cowpea breeding lines for production of flours for value-added foods where seed coat pigmentation is undesirable. The all-white varieties have potential in the United States as food companies seek ways to increase the nutritional content of low nutrient dense foods by augmenting them with legume flours and for cowpea value-added foods such as Akara from Africa. One advanced line, California Cream, has performed well in yield trials relative to standard black-eyed controls in California's Central Valley.

Cerotoma ruficornis

A series of advanced black-eyed lines was developed into which tolerance to attack by lygus pod sucking bugs has been introgressed from African cowpea sources. We also initiated a new round of crosses in 2010 for breeding varieties with increased resistance to lygus and high quality grain. We are breeding an improved version of the standard black-eyed *CB46* with greater resistance to root-knot nematodes, smaller grain size, and potential as a canning variety.



Cowpea yellow mosaic virus

Modern cowpea breeding resources
We continued to produce, maintain, and seed increase important cowpea populations for molecular-based breeding and genetic analysis of traits. Use of both Recombinant Inbred Line populations and sets of Near-Isogenic Lines led to discovery and genetic mapping of numerous quantitative trait loci (QTL) governing the important traits in cowpea: heat and drought tolerance, and resistance to root-knot nematodes, Fusarium wilt, ashy stem blight caused by Macrophomina, bacterial blight, foliar thrips and flower thrips, cowpea aphid, and the parasitic weed Striga. These genetic stocks have been used to provide elite lines that can be tested for yield potential and released directly as new varieties, and also crossed as trait donors into preferred local varieties.

Seed production and delivery systems
This work has focused on Burkina Faso and Senegal, in which the local cowpea seed systems are being strengthened through developing self-sustaining supply and distribution of breeder, foundation, and certified seed classes.

Burkina Faso

The primary effort has been to produce breeder seed, foundation seed, and certified seed of six newly released cowpea varieties (*IT98K-205-8l, Melakh, KVx421-2J, KVX442-3-25, KVx771-10* and *KVx735-33-2*) and seven existing varieties (*Gorom Local, KVx61-1, KVx396-4-4, KVx396-4-5-2D, KVx414-22-2, KVx745-11P*, and *Telma*). More than 40 tons of foundation seed was produced in 2012 and another 10 tons in the 2012–2013 off-seasons. More than three tons of breeder seed were produced in 2011. In 2012 about 250 to 900 kg of breeder seed of each variety was also produced. Part of the money obtained from sale of foundation seed in 2011 was used to support 2012 seed production activities to establish a self-sustaining plant seed production and delivery system. Seed-producer training—theoretical and practical—was conducted at two locations

Harvest CRSP Cawpea trial March 2012. Alto Capaca IIA Station, Benguela during the 2012 preseason involving 90 farmers (25 women), who were then guided in producing certified seed of the INERA improved cowpea varieties during the main season; this generated 35 tons of certified seed produced on 50 ha. Foundation seed of seven varieties was also produced during the 2012 growing season by individual seed producer farmers, farmers organizations, agro dealers, and NGOs.

Senegal

Training of farmers during the 2009, 2010, 2011, and 2012 seasons for certified seed production consisted of field selection, removal of off-types and diseased plants, and both harvest and postharvest handling.

Availability of foundation seed has been identified as a bottleneck for adequate seed supply. To overcome this, Dr. Cisse produced more seed to complement the foundation seed production by the ISRA seed unit at Bambey and to help identify the demand level for foundation seed and establish new certified cowpea seed growers. Training of farmers for certified seed production consisted of field selection, removal of off-types and diseased plants, and harvest and postharvest handling.

A meeting of cowpea scientists and breeders from Burkina Faso, Mali, Niger, and Senegal was held in Niger to discuss results from multiyear field evaluations, deliver planting seed of improved Senegal and Burkina Faso cowpea varieties, and discuss protocols for field testing. Advanced yield trials with eight selected varieties conducted in Burkina Faso at Saria and Pobé in the 2011 main season indicated that the Burkina Faso variety KVx30-309-6G and Senegal variety Melakh performed well and have potential for production in Niger. Foundation seed for the expansion of this variety in Niger is being bred.

POTENTIAL DEVELOPMENTAL OUTCOMES AND BENEFITS TO THE COWPEA VALUE CHAIN

We have continued to build on the core germplasm resources and associated trait knowledge required for genetic improvement in cowpea. Underpinning this effort has been the characterization of cowpea landraces and modern varieties through diversity analyses and genetic mapping for traits. A significant representation of the IITA minicore and USDA core cowpea collections have been SNP genotyped and phenotyped for numerous biotic and abiotic stress responses, and agronomic and grain quality traits. Numerous QTL determining important traits have been discovered. Improved varieties with pest and drought resistance will especially benefit poor farmers, many being women. We have continued to focus on developing early maturing varieties that provide the first food harvested following the dry season, breaking the hunger period.

To further expand the adoption of improved Pulse CRSP-developed cowpea varieties, coordinated trials were conducted to assess yield potential of improved Senegal and Burkina Faso cowpea varieties in neighboring Mali and Niger.

Grain quality has been a central selection criterion in our breeding programs, with the goal that new varieties are highly marketable and also useful for value-added foods commonly prepared in Africa and for traditional uses in the United States. Value-added foods from cowpea and other grain legumes are becoming an important focus for food processing companies as they seek to develop more nutritious foods, so we have continued to advance all-white cowpea grain types in Africa and the United States, which is especially attractive where cowpea flour forms the product's base.

Building on previous investments in cowpea genetic improvement, we have established stable partnerships with host country and IITA breeding programs in West Africa, which have facilitated successful leveraging of research and capacity building funds through the CGIAR Generation Challenge Program and the California Dry Bean industry.

The cowpea seed production and delivery systems in Burkina Faso and Senegal were strengthened through targeted training in the seed production system, to expand the adoption of improved cowpea varieties developed in the NARS programs. To broaden the impact, this activity was repeated in each of the primary cowpea production regions in Burkina Faso and Senegal and coordinated trials were conducted to assess yield potential of improved Senegal and Burkina Faso varieties in Mali and Niger. Some varieties performed exceptionally well in regions that share the same agroecology.

Our work in Angola has begun to re-establish a cowpea breeding program and we have determined the critical needs in improving the cowpea production system.

CONTRIBUTIONS TO INSTITUTIONAL CAPACITY BUILDING

… with the aid of leveraged funding, we have developed and shared genomic resources for use in cowpea research and breeding …

The cowpea improvement project focused on the cowpea breeding programs in Africa and, more broadly, cowpea researchers worldwide via training, germplasm and genomic resources distribution and sharing, and interactive breeding objectives. Pulse CRSP support has helped maintain the UC Riverside cowpea germplasm collection of 5,600 cowpea genotypes. We have provided the cowpea research and breeding community with important germplasm through about 100 distributions to numerous countries for use in basic research, applied breeding and evaluation trials, and for NGO development projects. We have also developed and shared genomic resources for use in cowpea research and breeding, and training in genomic resource applications.

Training has involved at least six graduate students, workshops for individual and small group cowpea breeders, and specific molecular breeding plans with NARS and IITA partners. A two-day workshop for cowpea and common bean breeders was held in 2012. Several African breeders trained at UC Riverside to advance knowledge in high throughput marker applications.

KEY PUBLICATIONS

Muchero, W., N.N. Diop, P.R. Bhat, et.al. 2009. 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.

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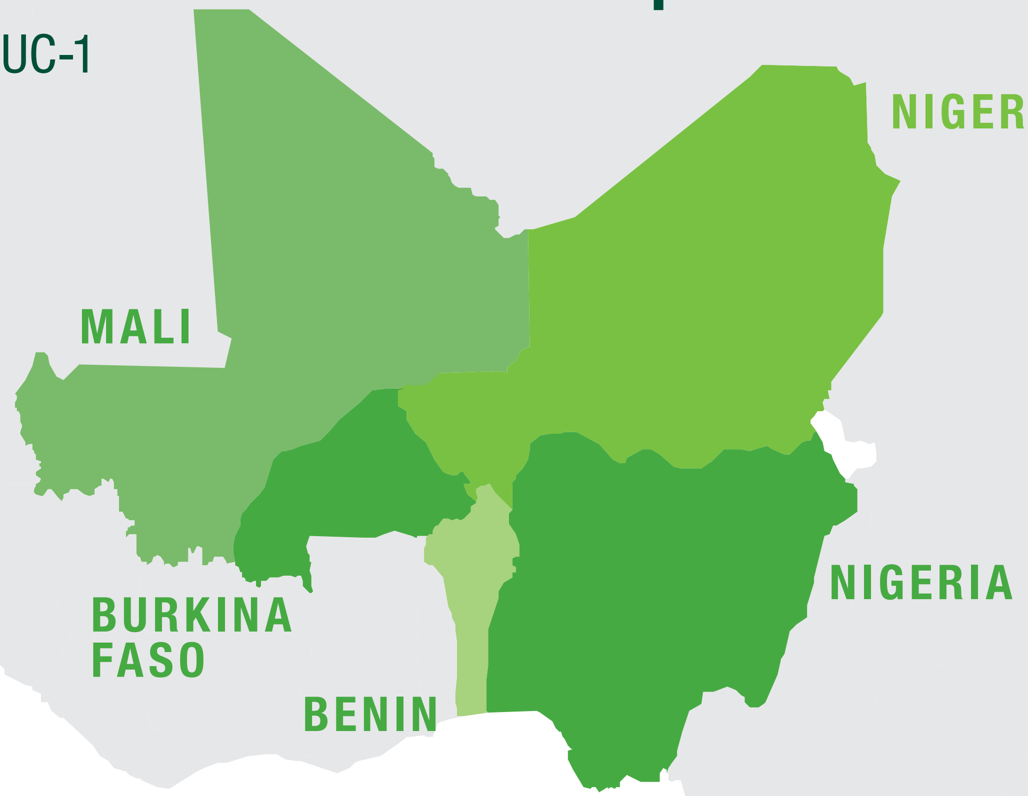
Pottorff, M., S. Wanamaker, Y. Q. Ma, J.D. Ehlers, P.A. Roberts, and T.J. Close. 2012. Genetic and physical mapping of candidate genes for resistance to *Fusarium oxysporum* f.sp. *tracheiphilum* race 3 in cowpea [*Vigna unguiculata* (L.) Walp]. *PLoS ONE* 7(7): 1–11.

Cerotoma ruficornis

Maruca testulalis

Biological Foundations for Management of Field Insect Pests of Cowpea in Africa

PII-UIUC-1



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More than two dozen other partner groups through the "Scientific Animations Without Borders" program

CORAF (Council for Agricultural Research and Development)

Center for African Studies (CAS), UIUC, USA

The ADM Institute for the Prevention of Postharvest Loss, UIUC, USA.

Mortenson Center for International Library Programs, UIUC, USA

Gemechu Olana, Adama Science and Technology University, Adama, Ethiopia

Robert Mazur, ISU, USA

ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

Insect pests of cowpeas dramatically reduce yields for cowpea farmers in West Africa. This program has laid the foundation for development and 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. We call this strategy, in which genomics tools are combined with an in-depth understanding of pest populations in the field to guide solutions and decisions for pest control, *IPM-omics*; this approach is safe for people and the environment. One outcome includes a neem extract (from local plants) and an insect-specific virus that, when combined, doubles the yield of cowpea—a yield gain better than conventional pesticides. New rearing and deployment systems for natural enemies (parasitic wasps) of cowpea pests (including pod bugs, thrips, and pod borers) that can easily be implemented by youth agribusinesses and women's self-help groups have also been created.

To get these innovations to farmers in rural areas who speak different languages, we have developed three-dimensional educational animated videos that can be voice-overlaid in many different languages and deployed into the field on various devices. Called *Scientific Animations Without Borders* (*SAWBO*), these videos are easily accessible on the Internet. SAWBO studies have demonstrated the in-field potential of this approach, and strategies for cost-effective deployment that empower local development groups have been developed.

We have trained many African and U.S.-based undergraduate and graduate students and empowered African and U.S.-based scientists through educational and research networks.

PROBLEM STATEMENT AND RESEARCH APPROACHES

The greatest biotic constraints on cowpea production are insect pests, requiring the deployment of pest control strategies to improve the livelihoods of cowpea producers and consumers. The most logical, long-term options for control of cowpea pests will be using a mix of biological control agents, cultural practices, biopesticides, and classic host plant resistance.

In the long run, pesticides are likely to become a less viable option for control of pests on cowpea due to their potentially health damaging impurities and low levels of active ingredients.

We now have numerous biological control agents against pests of cowpeas, and educational materials for promotion of other pest control strategies.

While host plant resistance traits and cultural practices will help control some of the pest species of cowpea (and are being pursued), they need to be complemented by other strategies that more immediately and directly reduce pest populations. For example, it could be another decade before Transgenic *Bt* cowpea, to control *M. vitrata*, is available. Physical approaches for insect control, such as triple bagging, have been developed and are being deployed for the control of bruchids in stored cowpeas, and many host country scientists promote the successful use of local plant extracts, such as neem, to suppress pest populations. While these approaches can be effective, their use often requires educational materials for numerous farmers in a given region or regions—a requirement that is not always easily met. Biocontrol agents, conversely, have the advantage that some can simply be released to suppress pest populations over the long-term without further human intervention, while others can be turned into cottage industries (e.g., viral sprays), thus representing immediate, tangible, and cost-effective solutions for farmers to control the pests that attack cowpeas in the field.

We now have numerous biological control agents against pests of cowpeas and educational materials for promotion of other pest control strategies (e.g., cultural practices and plant extract sprays) ready for release and testing on a pilot-scale to prepare for a large-scale deployment effort.

One of the challenges of releasing biocontrol agents has been determining where to release these organisms for the greatest impact. The best place is where the insects are endemic and can support the biocontrol agent populations and in endemic populations that cause the most damage in cowpea fields. To gain this understanding, insect populations must be monitored and molecular markers developed to determine insect movement patterns and verify the success of the biocontrol agent programs. The use of genomics tools to determine insect movement patterns with applications for integrated pest management is the emerging field of study *Integrated Pest Management-omics* (*IPM-omics*).

This past year, the SAWBO program has expanded rapidly to include more than two dozen partner groups around the world.

Our project aimed 1. to combine surveys of pest populations with genomic analysis tools to determine where best to release biocontrol agents against *M. vitrata*, 2. to develop the necessary expertise to extend these IPM-omics strategies to all other insect pests of cowpea, and 3. to develop the necessary capacity, institutional infrastructure, and farmer training for the strategic release of biological control agents for the pests of cowpeas in the next stage of our project. We are well positioned to develop a comprehensive IPM-omics tool set for the major pests of cowpea.

Lastly, we have developed and tested educational deployment strategies that will position us to deploy pest control strategies on a large-scale and in a cost-effective manner. We have spearheaded 1. cell phone-ready animations to train people in pest control strategies (SAWBO), 2. an online peer-review system for host county collaborators to share these educational materials (Sustainable Development Virtual Knowledge Interface) and 3) working relationships with other organizations that will allow us to scale up on-the-ground farmer education of IPM-based pest control strategies. This past year, the SAWBO program has expanded rapidly to include more than two dozen partner groups around the world. The animation technologies and deployment strategies have been used for cowpea-related activities in West Africa across multiple groups and this new technological approach has become a very researchable approach, in addition to being a potentially rapid and high impact deployment strategy.

ACHIEVEMENTS AND OUTPUTS

We have developed a biocontrol agent pipeline that has and will continue to allow us to systematically bring a series of biocontrol agents to minimize cowpea pest populations from initial testing to deployment in the field. This approach allows us to have and to continue to develop numerous pest control strategies which, combined in interchangeable ways in different agroecological regions, have the potential to suppress a complex of pest populations.

For the legume pod borer (*Maruca vitrata*) we have developed an extremely cost-effective rearing system (critical for a large-scale biocontrol program) using germinating cowpea grains; using cowpea grains for *M. vitrata* rearing is 25 to 30 times less expensive than the artificial diet rearing system. This cheap and locally available rearing method is currently being applied for mass production of both exotic parasitoids from Taiwan. The best results were obtained using the white seeded cowpea (specifically, the Benin local variety *Tewe*) that gave the highest larval survival rates and the least contamination with molds, with larval yields of more than 200 larvae per 150 grams of cowpea grains.

Additionally, IITA created a series of training videos to educate technicians at other institutions on best laboratory protocols to support the development of NARS-based biocontrol programs. All of these videos can be downloaded from our online educational deployment system (the Sustainable Development Virtual Knowledge Interface), described below, and the technicians can play these videos on their cell phones to educate themselves on these issues.

Two approaches for controlling this pest in the field have also been developed. One of our best-bet biocontrol agents is the parasitoid wasp *Apanteles taragamae*, which targets *M. vitrata* in the field and appears to be species specific. Detailed experiments indicate that this species disperses effectively—critical for its potential use in *M. vitrata* population management. To release

Figure 1. Impact of *Maruca vitrata* Multi-Nucleopolyhedrosis Virus (*Mavi*MNPV) on an *M. vitrata* larva.

A. taragamae, a nursery plot release method using naturally occurring patches of *T. platycarpa*, a weedy legume widely available in the Savannah area in Southern Benin and an important host plant for *M. vitrata*, was developed; the low material and labor costs make this a cost-effective deployment approach. For Burkina Faso and Niger, host plant studies have revealed logical regional host plants for biocontrol release programs.

A second control approach is the *Maruca vitrata* Multi-Nucleopolyhedrosis Virus (*Mavi*MNPV) (Figure 1). Discovered in Taiwan, *Mavi*MNPV is species specific for *M. vitrata* and does not effectively target other closely related insects in West Africa.

A detailed experiment was carried out in Benin comparing conventional spray with aqueous formulation of both neem oil and oil of *Jatropha curcas* mixed with the virus to control the other cowpea pests (*e.g.*, thrips, aphids) present in the field with *M. vitrata*. In the first season, the application of *Mavi*MNPV alone was able to control *M. vitrata*, producing a cowpea grain yield increase of 67.2 percent over the unsprayed control; the association of the virus with the aqueous formulation of neem oil, however, gave the best yield gain, 106.8 percent compared to the unsprayed plot and statistically superior to the chemical treatment at 65.9 percent (Table 1). IITA has actively been pursuing the development of cottage industries for women to create these biopesticides and income streams. A successful system has been set up for neem and efforts are in progress for *Mavi*MNPV.

Treatment	1st rainy season	2nd rainy season
Unsprayed control	522,95 ± 28,20a	282,00 ± 21,88a
Chemical control (Decis)	868,62 ± 68,09b	652,75 ± 62,94b
Neem oil	826,42 ± 52,80b	691,22 ± 22,18b
Jatropha oil	867,90 ± 28,29b	533,60 ± 45,31b
*Mavi*MNPV	875,12 ± 47,83b	545,07 ± 54,50b
Neem oil+ *Mavi*MNPV	1082,10 ± 58,78c	552,47 ± 27,32b
Jatropha oil + *Mavi*MNPV	1096,30 ± 26,05c	614,33 ± 11,34b
*Kg/ha	- High humidity - High Maruca density	- Dry conditions after flowering - Lower Maruca density in pods

Table 1. Cowpea Yield as affected by different pest control treatments in two different rainy seasons in Southern Benin*

These two systems represent those agents that are at the end of the biocontrol pipeline and ready for larger scale deployment and use in the field. We have many other biocontrol agents to be brought forward in this biocontrol pipeline for a next phase of the Pulse CRSP.

To optimize the success of these biocontrol agents cost effectively, we have spearheaded IPM-omics, particularly molecular tools coupled with rigorous field experiments to help facilitate IPM decisions related to pest control approaches. We have developed molecular markers to better understand pest movement patterns across four countries in West Africa. Our results for *M. vitrata* demonstrate that this pest is endemic as far north as Southern Burkina Faso and moves in a northerly direction during the rainy season. The resultant pest management decision is that biocontrol agents can be released as far north as Southern Burkina Faso and pest management strategies for farmers north of this area will need to involve training farmers in a neem plus *M. vitrata*-specific virus solution. In the latter half of the Pulse CRSP project, we successfully generated molecular markers for all other pests of cowpea in the field and will be using these markers to begin understanding the pest populations across multiple agroecological zones in the next phase of the project.

We used Farm Field Fora (FFF) as a successful mechanism to deploy information and technology into the hands of farmers. Two test FFFs were monitored and resulted in nearly doubling yield gains in the test plots. In Burkina Faso, the FFF were implemented and the farmers of the Gourcy district are now among the best cowpea producers in Burkina Faso.

One of the challenges we observed in our project was making the innovations we developed accessible to other educators and to farmers who speak different languages, live in rural areas, and are often low literate learners. The increased availability and ownership of cell phones with video capacity and Bluetooth® technology in many villages afforded significant potential for using cell phones to display and propagate educational content associated with pest control. To control for costs, we developed high quality, two- and three-dimensional animations to deliver educational content; as a bonus, we can easily voice overlay these materials in numerous local West African languages. Thus, we now have a system where educators can gain access to and easily deploy these educational animations in local languages.

Figure 2. Women from Niger watching an educational animation in their own language, Hausa, which explains how to prevent insect attack on cowpea seeds using a solar treating technology.

Through this program—Scientific Animations Without Borders—we have created educational content for four immediately useful pest control technologies in cowpea and tested various aspects of SAWBO videos in the field (Figure 2): acceptance and potential for learning, availability of deployment pathways, and increased adoption of technologies explained in the videos. We have also made these materials available to numerous outside groups to use as educational materials in their programs. Further scalable and cost-effective deployment strategies of these materials will be expanded in the next phase of the Pulse CRSP. SAWBO has received numerous private donations and funding from multiple groups to create educational content in many other areas of agriculture and public health, both within the United States and abroad.

We have also developed an online peer-reviewed system for deployment of educational content for sharing with other groups called the Sustainable Development Virtual Knowledge Interface (SusDeViKI), which allows educators to download materials useful in their educational programs with farmers in developing nations. Many of the materials can be directly downloaded and taken to educational programs on cell phones. The system contains more than 245 educational materials in dozens of different languages and more than 25,000 views and downloads of these educational materials have occurred.

A dead *Maruca vitrata* larvae; its death is due to the *M. vitrata*-specific virus, MaviMNPV, for this insect pest of cowpeas.

Both SAWBO and SusDeViKI allowed our Pulse CRSP team to easily partner with other government, NGO, and educational groups in a virtual manner, allowing us to create new and locally adapted materials for educational programs. INERA with partners (government and NGOs extension agents) in Burkina Faso have deployed videos for cowpea storage in the Zondoma and Sourou provinces. IITA has worked with local communities in Southern and Central Benin for validating and fine-tuning the animation videos in several local languages for neem extract production. They have also tested the spread of these animations from cell phone to cell phone, documenting the easy spread of these videos in communities. INRAN has deployed these videos to a minimum of 20,000 people in Niger along with field-testing these animations. SAWBO now has between two to three dozen partner groups in Africa and around the world who are actively using these materials. Additionally, we have had multiple individuals and NGOs simply download our materials, thanking us after their use, and multiple local institutions have cost-shared the local deployment, voice overlaying, testing, and use of these materials. Although much of this work has gone beyond cowpeas, this system allows us to easily reach out to new groups across a country and around the world who can adapt these materials and host them on their outreach systems. We have also worked with Dr. Robert Mazur to voice over these videos in East African languages for use in his Pulse CRSP project.

Finally, we fully recognized the need to couple all of these efforts with assessment programs on how to integrate these pest management solutions (and marketplace opportunities) into West African communities. We have performed multiple assessments of our videos across Benin, Burkina Faso, Niger, and Nigeria. We have also performed a study, in collaboration with Dr. Shumate at Northwestern University, on the interactions of development groups in Burkina Faso. We will continue to assess the impact of our work in the next phase of this project.

These studies have raised important research questions, with potential impacts for projects beyond our own; this study has also helped us establish strong collaborations with groups involved with impact assessment.

POTENTIAL DEVELOPMENTAL OUTCOMES AND BENEFITS TO PULSE VALUE CHAIN(S)

- A pipeline for developing low-cost, locally appropriate, and scalable solutions for pest management on cowpea crops, including a pipeline of biocontrol agents, host plant resistant lines, and techniques to manage pests.
- Multiple projects focused on linking our innovations with cowpea value chains in West Africa. For example, a youth agribusiness self-help commercial partner in Central Benin can produce a mixture of neem preparations and the insect-specific viral entomopathogen. The same self-help enterprise, involving women's groups, is currently acquiring and perfecting the process for the culture of the viral entomopathogen, using cheap production methodology involving rearing the pod borer larvae on cowpea sprouts.
- Trainable solutions for farmers and educational programs that can be developed and scaled for local deployment agencies to take to farmers in their own languages.
- IPM strategies with the potential to double the yield of cowpea in the fields in West Africa

CONTRIBUTIONS TO INSTITUTIONAL CAPACITY BUILDING

1. Creation of a biocontrol pipeline that involves two CGIAR centers and multiple West African NARS programs.
2. A genomics toolbox, including molecular markers for all pest insects of cowpeas, for studies that have and will continue to drive the development of appropriate IPM programs for cowpeas in West Africa.
3. Considerable senior scientist cross-training, including a six-month training session for Dr. Malick Ba at University of Illinois, who developed skills in molecular biology bench work and analysis tools as well as computational modeling of risk assessment as associated with transgenic plants that has made him a key expert on transgenics and risk assessment in Burkina Faso.
4. Training of more than 10 M.S. and Ph.D. students and numerous undergraduates both in West Africa and at UIUC, more than 40 percent of whom are women.
5. Tolulope Agunbiade, a student from Nigeria studying at UIUC, received the prestigious Howard Hughes Medical Institute predoctoral fellowship (for three years) for her outstanding contributions to UIUC's Pulse CRSP project.
6. An IITA- and INRAN-hosted training program for technicians to receive cross-training on laboratory and field-related activities critical for the biocontrol pipeline.
7. Training of local NGOs and the Peace Corps in IPM and how to perform FFF.
8. Multiple farmer training programs through FFF every year in Niger, Mali, Nigeria, and Burkina Faso.
9. Founding of SAWBO to rapidly develop new educational materials that can be voice overlaid in many languages and used on multiple electronic devices.
10. The development of SusDeViKI to share easily downloadable educational materials online for low literate learners in their own language.

Man watching solar drying video

11. IITA training videos on insect and biocontrol agent rearing in the laboratory, readily available through SusDeViKI and IITA directly.

12. Both biocontrol agents and biopesticide approaches are now available to the NARS research and educational programs for scaling.

13. Key collaborations are in place for impact assessment to better direct our research and education to optimize future activities.

14. IITA and our collaborating NARS programs have leveraged resources from the Pulse CRSP program to seek and obtain other funding.

15. Production of more than 1,000 SAWBO video CDs for distribution by UIUC faculty traveling to West Africa.

16. Multiple SAWBO websites for easy downloading of SAWBO videos (http://sawbo-illinois.org/main.htm). The SAWBO and SusDeViKI systems have had more than 100,000 downloads/views in the last year. We also distributed these videos to groups that count tens of thousands of people exposed in the field.

KEY PUBLICATIONS

Agunbiade, T.A. Kim, K.S., Forgacs, D. Margam, V.M., Murdock, L.L., Ba, M.N., Binso-Dabire, C.L. Baoua, I. Ishiyaku, M.F., Tamò, M., and Pittendrigh, B.R. 2012. The spatial genetic differentiation of the legume pod borer, *Maruca vitrata* F. (Lepidoptera: *Pyralidae*) populations in West Africa. *Bulletin of Entomological Research* 17:1–11.

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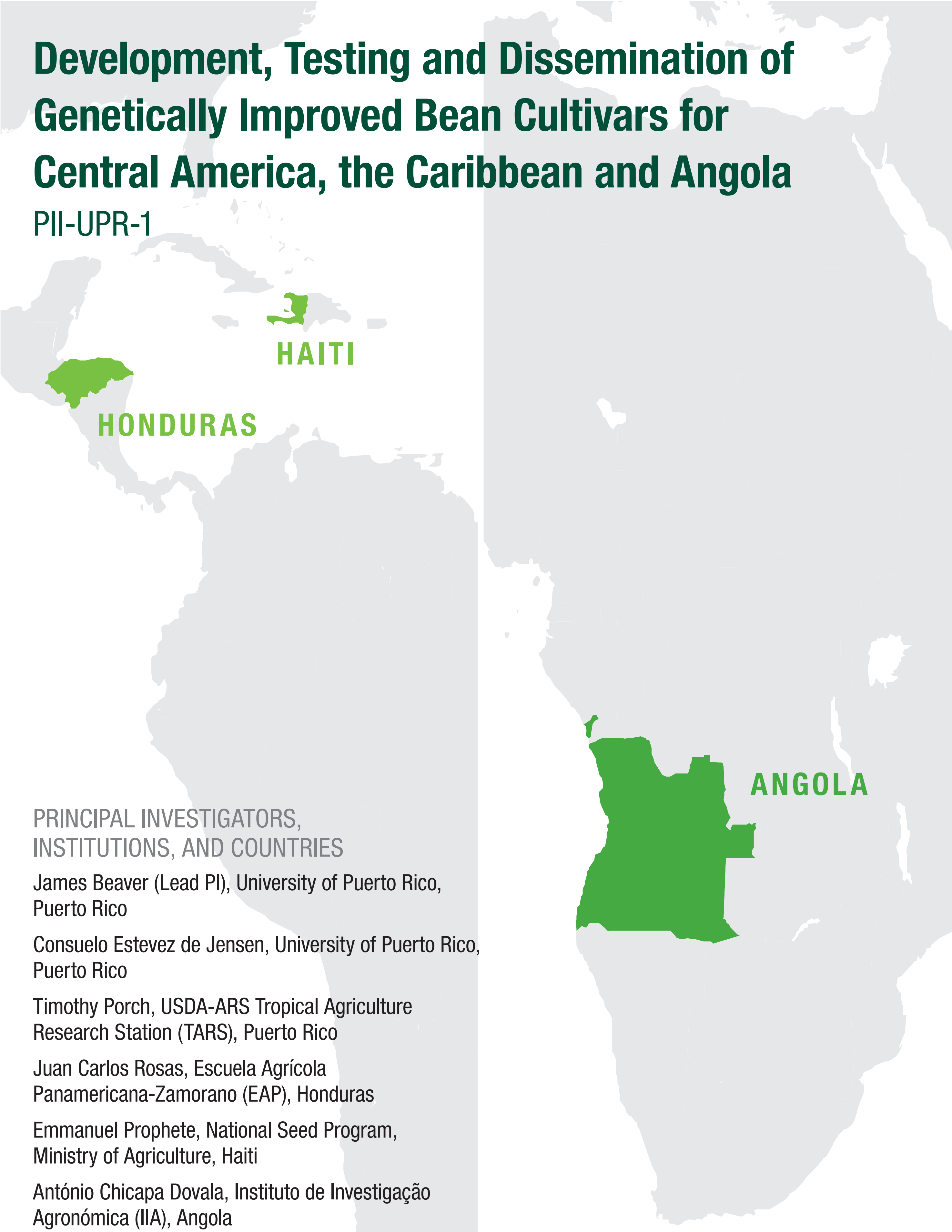
Development, Testing and Dissemination of Genetically Improved Bean Cultivars for Central America, the Caribbean and Angola

PII-UPR-1



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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

Significant progress was made during the past five years toward research and training objectives. Disease resistant small red, black, white, and red mottled bean cultivars were developed and released in Central America and Haiti and have been widely adopted by more than 100,000 farmers in the region. The Bean Technology Dissemination project facilitated the distribution of seed and *Rhizobium* inoculant. Bean germplasm lines that combine resistance to biotic and abiotic stresses were also developed through cross breeding and marker-assisted selection (MAS). Populations were developed to study the expression of nodulation and N2 fixation traits. Significant *Rhizobium* strain x bean line interaction for seed yield was observed in field trials. Lines were identified that nodulated and yielded well when inoculated with different *Rhizobium* strains (CIAT899 or UMR1597). Project identified the dominant gene, *Xap-1*, that confers resistance to common bacterial blight (CBB). Preliminary results suggest that additional genes need to be introgressed to achieve high levels of CBB resistance. The response of common bean to ashy stem blight was evaluated in the field and greenhouse. The web blight and root rot reactions of nine *Rhizoctonia solani* isolates from bean leaves and roots were studied in the greenhouse. There were significant bean line x isolate interactions for both web blight and root rot reactions. We observed significant differences among Lima bean landrace varieties from Haiti, the Dominican Republic, and Puerto Rico for seed type, leaf, and pod type; days to flowering; seed yield; and concentration of HCN in the leaves and seed. The Caribbean collection of Lima bean landraces was sent to CIAT for preservation in their germplasm collection. The diversity of Angolan Cowpea germplasm, in relation to a diverse worldwide collection, was also evaluated. Results indicated some unique nutritional characteristics of Angolan germplasm, including high protein and iron content. Tepary breeding lines were developed from crosses between elite germplasm, resulting in lines with increased seed size, improved architecture characteristics, and bacterial blight resistance. Two tepary lines with superior performance (drought tolerance and common blight and bruchid resistance) were released as improved germplasm.

Six students completed M.S. degrees in plant breeding at the University of Puerto Rico. Ten students completed B.S. degrees at Zamorano. This Pulse CRSP project sponsored workshops at Zamorano and Mozambique concerning biological nitrogen fixation techniques, including the production of *Rhizobium* inoculant. Workshops describing bean breeding research techniques were held at Zamorano and Angola. Vehicles were purchased for the bean research programs in Haiti and Angola, and funds were used to improve plant pathology laboratory and greenhouse facilities in Angola.

PROBLEM STATEMENT AND RESEARCH APPROACH

Common bean is an important source of protein for low income families in Central America, the Caribbean, and Angola. Increased or more stable bean yield can improve the diet and provide a reliable source of income for small-scale farm families in these countries. An increased supply of beans also benefits urban consumers.

The development of improved common bean varieties has proven to be an effective strategy to address biotic and abiotic factors that limit bean production. During the past 20 years, there has been a lower level of investment in breeding, testing, and dissemination of black beans by national bean research programs. As a consequence, black bean cultivars tend to have lower seed yield potential and less disease resistance than the more recently released small red bean cultivars. The most promising small red bean cultivars developed at Zamorano can be readily used to improve black beans. During the past five years, the Pulse CRSP project developed a sizeable number of black bean breeding lines that have been distributed to bean research network members in Nicaragua, Guatemala, and Haiti. The project also developed and released Andean (red mottled, yellow, and light red kidney) bean breeding lines with resistance to BGYM, BCMNV, and other diseases of economic significance.

Because many small red and black bean breeding lines with enhanced disease resistance and tolerance to abiotic stress were in an advanced stage of development, the Pulse CRSP project collaborated with an established network of bean researchers in Central America to test, release, and disseminate improved bean cultivars. The project also trained researchers in Angola.

Given their similarity in agroecological zones and production constraints, improved bean breeding lines developed in Central America and the Caribbean have proven useful in Angola. Some small red and black bean cultivars and breeding lines developed in Central America and the Caribbean have resistance to diseases and tolerance to abiotic stresses that are significant constraints to bean production in Africa. Central American bean breeding lines with resistance to BCMNV, common bacterial blight, and web blight may be of particular value to northeastern Angola or Tanzania, where small red beans are produced. Although black beans account for less than five percent of bean production in Africa, this seed type is often a component of mixtures grown in low fertility soils and are often the highest-priced seed type in Luanda's markets. The lowland bean breeding team has also developed Andean (red mottled, yellow, and light red kidney) bean breeding lines with resistance to BCNMV and rust that may be useful in Eastern Africa. Angola may benefit from testing the bean breeding lines that have resistance to BCNMV and rust. We collaborated with other Pulse CRSP projects and CIAT in evaluating improved bean cultivars and breeding lines from the United States, Central America, and the Caribbean.

ACHIEVEMENT AND OUTPUTS

Development, release, and dissemination of improved bean cultivars for Central America, the Caribbean, and Angola

The project has made significant progress in the development and release of improved bean cultivars and the release of improved bean germplasm (Table 1).

Table 1. Release of common bean cultivars in Central America and the Caribbean, 2007 to 2012.

Cultivar or germplasm line identification	Seed type	Country of release	Traits
INTA Centro Sur	Red	Nicaragua (2013)	Resistance to BGYMV (bgm), BCMV (I), tolerance to low fertility
MEN2201-64 ML	Black	Haiti (2013)	Resistance to BGYMV (bgm), BCMV (I) BCMNV (bc-3)
XRAV-40-4	Black	Haiti (2013)	Resistance to BGYMV (bgm), BCMV (I) BCMNV (bc-3)
PR0737-1	Red mottled	Haiti (2013)	Resistance to BGYMV (bgm), BCMV (I) BCMNV (bc-3)
CENTA Chaparrastique	Red mottled	El Salvador (2011)	Resistance to BGYMV (bgm), BCMV (I), high yield potential, good seed type
Beníquez	White	Puerto Rico (2011)	Resistance to BGYMV (bgm), BCMV (I) BCMNV (bc-3)
Badillo	Light red kidney	Puerto Rico (2010)	Resistance to BCMV (bgm), CBB and heat tolerance
ICTAZAM	Black	Guatemala (2010)	Resistant to BGYMV (bgm & QTL), BCMV (I) and web blight
ICTA Sayaxche	Black	Guatemala (2010)	Resistant to BGYMV (bgm & QTL), BCMV (I) and rust, high yielding
INTA Matagalpa	Small red	Nicaragua (2010)	Resistant to BGYMV (bgm & QTL), BCMV (I) and rust, high yielding
IDIAF DPC-40	Black	Dominican Republic and Haiti (2009)	Resistance to BGYMV (bgm), BCMV (I) BCMNV (bc-3)
Aifi Wuríti	Black	Haiti (2009) Guatemala (2010)	Resistance to BGYMV (bgm), BCMV (I), earliness
Verano	White	Puerto Rico (2008)	Resistance to BGYMV (bgm), BCMV, CBB and heat tolerance
CENTA Nahuat & CENTA CPC	Small red	El Salvador (2008)	Resistant to BGYMV (bgm and QTL) and BCMV (I), heat tolerant
Cardenal and DEHORO	Small red	Honduras (2007)	Resistant to BGYMV and BCMV (I)
PR0401-259 and PR0650-31	Pink and black	UPR and USDA/ARS	Resistant to BGYMV (bgm) and BCMV (I), web blight and common blight
TARS-MST1 and SB-DT1	Black	USDA/ARS, UNL, UPR (2012)	Heat tolerance, root rot resistance, common blight, BCMV (I)

Development of breeding populations

Small red, black, white, and Andean bean breeding populations were developed and evaluated over the past five years, some for improved adaptation to the highlands of Honduras, Guatemala, and Haiti; others for the lowlands in Central America and Haiti; and others for Angola.

All of the Angolan landraces were susceptible to CBB and BCMV, and largely to ALS. Several of the Angolan lines, however, showed good BNF potential.

Crosses were made in Honduras to improve small red landraces carrying the *Rojo de Seda* bean seed type for Central America and black bean cultivars for Guatemala and Haiti. The cultivar *Seda* is an early maturing, well adapted Honduran small red landrace with tolerance to drought and low fertility that nodulates well. Populations derived from crosses include local landrace cultivars. The performance of breeding lines derived from crosses between landraces from El Salvador, Honduras, and Nicaragua and improved cultivars to improve the most common Honduran small red bean landraces and the widely grown Salvadoran landrace Rojo de Seda was validated in Honduras.

Germplasm collected in Angola representing predominant market classes (medium sized yellow, green, and white types; and large seeded cranberry and kidney types) grown in the major common bean growing regions of Bie, Huambo, Cuanza Sul, and Malange provinces were evaluated in Puerto Rico. All of the Angolan landraces were susceptible to CBB and BCMV, and largely to ALS. Several of the Angolan lines, however, showed good BNF potential. Lines that are adapted to Angola and have resistance to BCMV, BCMNV, CBB, and ALS were selected. Populations were developed from crosses between the commercial seed types used in Angola and sources of disease resistance, particularly CBB and BCMV.

The yellow bean is a preferred seed type in Haiti and Angola. MAS and greenhouse evaluations were conducted to identify lines with genes for BGYMV and BCMV resistance.

The common bean weevil is a major seed storage pest. The University of Puerto Rico received black and light red kidney breeding lines that were expected to segregate for resistance to the bean weevil; a bioassay was developed to screen them. Three of the light red kidney lines showed useful levels of resistance. The common bean weevil-resistant red kidney line AO-1012-29-3 was crossed with black, small red, white, and red mottled bean breeding lines having BGYMV, BCMNV, and BCMV resistance. Bruchid resistant lines were screened for resistance to BGYMV and BCMV, and seed of lines that combine bruchid and virus resistance were increased. Small seed samples of bruchid resistant lines were distributed to collaborators in Central America, Haiti, and Ecuador.

Regional performance trials

Advanced bean breeding lines were derived from crosses between disease resistant and abiotic stress tolerant parental lines from Zamorano, the UPR, USDA-ARS-TARS, CIAT, and National Bean Programs (NBP). These lines have resistance to the major diseases and enhanced tolerance to at least one abiotic factor, good agronomic adaptation, and commercially acceptable seed type.

Numerous trials, including drought and heat tolerant small red and black bean cultivars and breeding lines from the CA/C region, were distributed to the NBPs of Costa Rica, Honduras, Panamá, Nicaragua, El Salvador, Guatemala, and the Dominican Republic to select for climatic change adaptation. ERMUS trials including web blight resistant lines from the first and second cycle of recurrent selection were distributed to NBPs in CA/C. These entries are also resistant to BGYMV and BCMV and have good agronomic adaptation and desirable commercial red seed type. The project is developing small red and black breeding lines that combine resistance to BGYMV and BCMV, and tolerance to drought and low fertility with resistance to angular leaf spot.

The UPR developed red mottled bean lines that combine resistance to BGYMV, BCMNV, BCMV, and common bacterial blight. PR0633-10 and PR0737-1 were among the highest yielding lines in the trials; both have the *bgm-1* gene for resistance to BGYMV and the *bc-3* gene for BCMV and BCMNV resistance. PR0633-10 also has the SW12 QTL associated with resistance to BGYMV and the SAP6 QTL associated with common bacterial blight resistance. PR0633-10 and PR0737-1 produced mean seed yields as great as or greater than check varieties PC-50 and JB-178. PR0633-10 and PR0737-1 are candidates for release as cultivars in Haiti and should serve as useful sources of resistance to BGYMV, BCMV, BCMNV, and common bacterial blight.

Five white bean breeding lines have resistance to BGYMV, BCMV, BCMNV and rust. These white lines had less powdery mildew that most other bean lines in the DR during the 2011–2011 growing seasons. All of the lines are moderately susceptible to angular leaf spot in Puerto Rico. Mean seed yield of the breeding lines was similar to the checks Verano and Morales. These lines will be considered for release as improved bean germplasm.

Lines developed for Central America and the Caribbean were evaluated in field trials in Angola during the main production seasons. Results from these trials helped identify economically important diseases in different regions in Angola and lines with different seed types that were well adapted, had good yield potential, and were disease resistant.

On-farm validation of promising breeding lines

Lines developed for Central America and the Caribbean were evaluated in field trials in Angola during the main production seasons. Results from these trials helped identify economically important diseases in different regions in Angola.

On-farm validation trials were conducted in Central America. The PASEBAF validation trial included drought and low fertility tolerant lines. Agrosalud lines, including small reds with greater mineral content (iron and zinc), were released as cultivars in Nicaragua and El Salvador. One small Agrosalud line was released as the cultivar *Chepe* in Honduras. The cultivar INTA *Fuerte Sequía* was released in Nicaragua, and the small red cultivars *Campechano JR* and *Don Kike* were released in Honduras.

Increased interest in the production of small red beans for export to El Salvador in Guatemala requires cultivars with higher yield potential and greater disease resistance. Ten of the most promising small red bean cultivars and breeding lines from Central America were sent to Guatemala for testing. Packages of seed of five of the most popular improved small red cultivars from El Salvador and other Central American countries were provided for on-farm validation in Guatemala.

Zamorano collaborated in the evaluation of small red bean cultivars and promising bean breeding lines for adaptation to the western region of Honduras—for highland and lowland to intermediate conditions. Three small red cultivars selected from the trial by participating farmers are being tested in on-farm validation plots.

Release of cultivars and seed multiplication

The black bean variety DPC-40, which combines resistance to BGYMV, BCMNV, and BCMV and is produced in the Dominican Republic was released by IDIAF. In 2011 and 2012, the National Seed Service in Haiti produced 10 MT of DPC-40 for distribution in Haiti. During 2012, more than 200 kg of basic seed stocks of BGYMV, BCMNV, and BCMV resistant black bean lines were produced in Honduras and shipped to Haiti for further multiplication.

Three small red cultivars were released in Honduras and four in El Salvador. All are very well adapted to conditions in these regions. The small red cultivar *Paisano PF* was released in Honduras in 2010. The small red cultivar *CENTA Chaparrastique* was released in El Salvador as a BGYMV and BCMV resistant, high yield potential cultivar with commercially desirable seed type. The black bean cultivars *ICTA Petén* and *ICTA Sayaxché* were released and disseminated in Guatemala.

Selection of beans for adaptation to low N soils

Greenhouse trials were conducted in Honduras to identify lines with better performance under low N conditions by expressing greater nodulation and BNF along with other mechanisms that allow beans to have greater accumulation of dry matter and seed yield under low N. The best nodulation was observed in the *Rhizobium*-inoculated treatment without N; and the greatest root, shoot, and total plant dry weight were observed in the + N treatments.

Experiments were conducted in Honduras to study the response of selected genotypes to inoculation with *Rhizobium* strains CIAT 899 and CIAT 632 and to identify potential parents for a recurrent selection program for high nodulation and N_2 fixation; parents with a greater response to a wide array of strains capable of nodulating common bean plants more effectively were identified. Additional BNF studies in Honduras included testing the response of 50 inbred-backcross (IB) lines to inoculation with strains CIAT 899 and CIAT 632 under low fertility conditions.

Populations from the Cycle 2 of recurrent selection for increasing BNF in common beans were developed from crosses between 24 lines selected from the screening of 250 F_4 families from 25 bean populations from Cycle 1 in Honduras under greenhouse conditions. The most promising F_4 families from Cycle 2 were evaluated for desirable agronomic and commercial traits.

Field experiments conducted over a two-year period in Puerto Rico identified four black bean breeding lines that combine disease resistance with greater N efficiency and superior performance in low N soils.

The nodulation patterns of 20 bean lines selected from previous studies for adaptation to low N were characterized in a low N soil using inoculation with three *Rhizobium* strains. Differences in nodulation, root traits, plant growth, and yield were observed among the cultivars and lines. Results will be used to identify the most useful cultivars and lines for further hybridization and selection for greater nodulation and better adaptation to low N soils.

Improved small red and black lines from regional trials were tested under inoculation with a mixture of three *Rhizobium* strains in unfertilized soil under drought stress. In general, nodulation, plant growth, and seed yield were lower; however, a few small red and black breeding lines and the landrace cultivar Seda performed well under these conditions

A set of 17 Mesoamerican and 15 Andean bean genotypes were tested to develop a set of differential genotypes for evaluating the response of *Rhizobium* strains and bean germplasm in diverse soil and climatic conditions. Preliminary results indicate a wide variation in nodulation to specific and mixtures of *Rhizobium* strains in inoculants.

Field experiments conducted over a two-year period in Puerto Rico identified four black bean breeding lines that combine disease resistance with greater N efficiency and superior performance in low N soils. Seed of these lines was sent to Haiti and Honduras for further evaluation.

Common bean is naturally nodulated by different *Rhizobium* strains, the most important being *R. tropici* (CIAT 899) and *R. etli* (UMR 1597). Successful introduction of inoculants depends on an efficient interaction between the *Rhizobium* strain and the *Phaseolus* genotype. Bean cultivars and bean breeding lines were evaluated for their efficiency to nodulate with *R. tropici* and *R. etli*. Among the genotypes evaluated, the Andean line PR9745-232, the pink line PR0401-259, Pinto line 10IS-2417, and DPC-40 nodulated well with CIAT 899; the pink line and Pinto line 10IS-2417 also nodulated with UMR 1597. Two Middle American lines nodulated only with UMR 1597. The greatest number of nodules was produced in lines PR0401-259 and 101S-2423. Considering that no fertilizer was applied to the trial, seed yields were excellent.

Competition with the established rhizobial population is a factor that can limit the success of an inoculant. The effectiveness of inoculants produced with single strains and/or a combination of different *Rhizobium tropici* and *Rhizobium etli* strains was evaluated. The mean nodulation score of *Rhizobium tropici* CIAT 899 in combination with the Isabela 1 strain was 5.7 (one to nine scale). Nodule size ranged between a one and three mm diameter and most of these nodules were located in the upper five cm of the root. Another combination of *Rhizobium* strains that produced outstanding nodulation due to the size and location of nodules was CIAT 899 and UMR 1597. The noninoculated control had the lowest number of nodules. Both combinations of *Rhizobium* strains and the NPK treatment produced the highest seed yields whereas the noninoculated control had the lowest grain yield.

As a result of the advances in the identification of superior *Rhizobium* strains and implementation of the inoculant production technology, extensive testing and dissemination activities were conducted in Honduras, Guatemala, Nicaragua, and Haiti. More than 2,000 farmers received small bags to inoculate their bean fields with a mixture of the best *Rhizobium* strains in Central America.

Development of molecular markers for disease resistance genes

The RAPD markers previously reported as linked to genes for charcoal rot were screened with a set of seven susceptible and eight resistant genotypes. The putative RAPD markers were proven to be ineffective, so recombinant inbred lines (RILs) from crosses between BAT 477 and susceptible bean lines were pursued for the development of novel markers. These lines were planted over 2008–2010 in a replicated field trial inoculated with the pathogen. The disease reactions of the RILs will be used to initiate the search for molecular markers for resistance to ashy stem blight.

More than 2,000 farmers received small bags to inoculate their bean fields with a mixture of the best Rhizobium strains in Central America.

A detached leaf technique for *Macrophomina phaseolina* evaluation has been implemented for screening the BAT 477 x DOR 364 RIL population. Significant differences were found among RILs in the population and some lines were identified in which seed yield and detached leaf score corresponded. A new RIL population is also being generated for the evaluation of Macrophomina.

USDA/ARS/TARS and UPR scientists collaborated in the identification of the dominant gene *Xap-1*, which confers resistance to common bacterial blight of beans. The SCAR marker SAP 6 co-segregates with this resistance gene.

The ENM-FWe/RVe primers, linked to the *bc-3* gene, were optimized for amplification at the USDA-ARS. The primers were found to be associated with the *bc-3* gene in known genotypes of common bean through a CAPs assay. Preliminary results suggest that this marker has potential for use in marker-assisted selection.

Rhizoctonia solani (Rs) is a widespread soil borne pathogen of common bean that can cause web blight (WB) or root rots, depending on its anastomosis groups (AG). Nine *Rs* isolates from bean plants expressing WB or RR symptoms were compared and used to inoculate the roots of the differential bean lines. *Rs* isolated from bean plants expressing WB symptoms were able to induce RR symptoms and vice versa. Significant line x isolate interactions were observed for the detached-leaf inoculation; root rot inoculations for the three planting dates suggested a differential response of the host to the pathogen. RR readings were generally more severe than WB readings.

Evaluation of other pulse crops for Central America and the Caribbean

Morphological, phonological, and agronomic traits of 55 Lima bean landrace varieties from Haiti, the Dominican Republic, and Puerto Rico were evaluated at Isabela, Puerto Rico, to ascertain the genetic diversity of the landrace varieties using molecular markers. Seed samples of the Lima bean landraces were sent to CIAT for long-term storage. Seed of the complete collection of Lima bean varieties was also shared with collaborators in Haiti and the Dominican Republic. Seed of one photoperiod insensitive landrace was multiplied and will be distributed to farmers in Haiti.

Seventeen lima bean accessions from the UPR collection were screened for adaptation in Honduras. When planted in Honduras in June, four landraces flowered less than 60 days after planting. The 12 most promising accessions continue to be evaluated.

The diversity of Angolan cowpea germplasm in relation to a diverse worldwide collection was evaluated for general adaptation, phenology, growth habit, yield components, seed characteristics, and elemental composition of the seed in field trials at Isabela, Puerto Rico, in 2010, and in Mazozo, Angola, in 2012. Angolan bean landrace varieties were identified that produced more than 1,000 kg/ha during both growing seasons in Puerto Rico. Seed of the most promising cowpea lines from this thesis research was planted in Haiti.

Nineteen cowpea lines were screened for adaptation in Honduras and seven relatively short-season lines were selected for further evaluation in Central America. Seed of the best red seeded cowpeas accessions were increased for distribution to collaborators.

Superior lines of tepary beans were evaluated in trials in Puerto Rico and Nebraska in 2007 and 2008, and adapted, large-seeded lines were selected for population development. Two of these lines were released and have been distributed to programs in Burkina Faso, Angola, Rwanda, Mozambique, Honduras, Haiti, and the United States.

POTENTIAL DEVELOPMENTAL OUTCOMES AND BENEFITS TO PULSE VALUE CHAIN(S)

Increased or more stable bean yields contribute to economic growth and improve the lives of the families who produce them, which fosters stability in Latin America, the Caribbean, and Angola.

Bean research in Central America and the Caribbean can help identify emerging bean diseases, permitting researchers to respond more rapidly and effectively when new diseases threaten bean production in the United States.

Lines with resistance to bean diseases, such as rust and common bacterial blight, should be useful germplasm for U.S. bean breeding programs.

The development and release of bean cultivars with enhanced disease resistance and greater tolerance to abiotic stress should reduce production costs and risk for bean producers in Central America, the Caribbean, and Angola. Lines with resistance to bean diseases, such as rust and common bacterial blight, should be useful germplasm for U.S. bean breeding programs.

Participatory plant breeding methods and multiplication of basic stocks on underutilized research stations has resulted in more sustainable seed production and distribution systems in some rural communities in Central America.

Formal and informal training has strengthened the capacity of the bean research programs in Central America, the Caribbean, and Angola.

CONTRIBUTIONS TO INSTITUTIONAL CAPACITY BUILDING

Training and improvement in infrastructure enhance the capacity of collaborators in Central America, the Caribbean, and Angola to conduct bean research and to disseminate improved cultivars and other technologies such as *Rhizobium* inoculant to farmers.

KEY PUBLICATIONS

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Enhancing Biological Nitrogen Fixation (BNF) of Leguminous Crops Grown on Degraded Soils in Uganda, Rwanda, and Tanzania

PIII-ISU-2

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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

Efforts focused on developing and characterizing a genetic diversity panel comprised of lines of Andean origin, which was called the Andean Diversity Panel (ADP).

The first strategic aim was to improve BNF and seed yields of common beans significantly using superior seed inoculants and improved varieties. Tests were conducted at research stations in each host country that showed considerable variation in yield among genotypes and locations in response to rhizobia inoculant and phosphorous fertilizer in the field trials conducted in Uganda, Rwanda, and Tanzania. This observed variability prompted additional investigations. Soil analysis revealed extreme deficiencies in macro- and micronutrients at most test sites—and tests of the relative effectiveness of soil rhizobia populations from these sites were almost devoid of active rhizobia. Finally, persistently low yields (20 percent of potential) were correlated with low plant populations at harvest. Clearly, these soil chemical and physical limitations needed to be overcome to resolve the soil biological limitation to BNF. (One fairly consistent result, however, was the positive response of high yielding climbing bean varieties grown under intensive management conditions.)

The second strategic aim was to examine the inheritance of genetic and environmental variation in BNF in common bean. Efforts focused on developing and characterizing a genetic diversity panel comprised of lines of Andean origin, which was called the Andean Diversity Panel (ADP). Characterization of the ADP in diverse environments allowed more efficient selection of parental materials for bean improvement. Seed of the accessions has been increased twice and distributed to at least six bean projects. The ADP also has served as an excellent platform for training scientists and will continue to be developed and distributed for many different phenotypic traits.

The third strategic aim was to improve the productivity, profitability, and sustainability of agricultural systems on degraded soils through effective dissemination of BNF technologies to smallholder farmers. Hundreds of smallholder farmers received direct training on BNF technologies and thousands of households received inoculant packets for testing. Hundreds of undergraduate students were trained on BNF through tours and internships.

Seven graduate students were trained at U.S. and HC universities with thesis topics related to the genetics, physiology, and agronomy of BNF in common beans.

PROBLEM STATEMENT AND RESEARCH APPROACH

Common beans are the most important legume crop in Uganda, Rwanda, and Tanzania. More than 45 percent of the protein intake (25 percent of dietary calories) by Ugandans comes from beans. More than 75 percent of rural households in Tanzania depend daily on beans, with common beans providing about 38 percent of utilizable protein (12 to 16 percent of daily calories) for low-income families. Improved bean production offers a unique opportunity to address the deteriorating food security situation.

Loss of soil fertility is recognized as the most important constraint to food security in sub-Saharan Africa, with low levels of nitrogen and phosphorous the primary fertility constraints. An affordable means of improving soil fertility and the productivity of nitrogen-accumulating crops is critical. Properly nodulated legumes can leave up to 350 kg nitrogen per hectare in the soil. Because inoculum is much cheaper than inorganic fertilizer, use of inoculants can provide an affordable and sustainable way to improve production of nitrogen fixing legumes.

Numerous studies have shown the potential of improving legume productivity by enhancing nodulation through a biological inoculant, yet field trials in sub-Saharan Africa have provided mixed results. The likely causes for variable response include poor quality control of inoculant formulation, failure to compete with local rhizobia, inhibition by indigenous microbial flora, and failure of the inoculant species to survive in low pH and/or droughty soils. Modern inoculant formulations designed to deliver a synergistic suite of biological and chemical enhancements for biological nitrogen fixation under stressful soil conditions have been made available to our collaborative research project by Becker Underwood, Inc's **BioStacked®** inoculant technologies for legume crops, which consist of well stabilized *Rhizobium* bacteria, a biological fungicide, plant growth promoting rhizobacteria, and other biologically derived proprietary biostimulant technologies that promote plant growth and overall plant health. These stacked inoculants have been shown to decrease chemical fertilizer use in crop rotations, increase legume yields, suppress root diseases, and improve rhizosphere conditions for root growth.

To optimize BNF, it is essential to identify the germplasm with the greatest capacity for this trait. Although common bean has the potential for BNF, it is reported to have the lowest percent N2 derived from N fixation among legumes. Genetic variation for BNF has been reported within the primary gene pool, and lines with superior BNF have been identified. Superior BNF lines have been used as parents in crosses to generate populations for genetic studies and to examine selection and breeding for improved BNF. Few breeding lines with improved BNF, however, have been developed.

Marker-assisted selection (MAS) under such conditions is highly sought after as a means to facilitate breeding for traits like BNF with low to moderate heritability. Molecular mapping in combination with germplasm screening and MAS would be a powerful way to improve locally adapted germplasm for BNF. Recombinant inbred populations currently available are ideal for tagging and mapping genes that influence quantitative traits (QTLs). Few QTLs associated with BNF, however, have been identified, and those identified have not been validated. Identifying and validating QTL-conditioning-enhanced BNF would represent a major step toward effective MAS for BNF.

Our objectives address the need to identify production systems that enhance BNF, develop germplasm that benefits most from symbiotic inoculation, and aggressively share this new information with smallholder farmers in sub-Saharan Africa.

ACHIEVEMENTS AND OUTPUTS

The first strategic aim was to improve BNF and seed yields of common beans significantly using superior seed inoculants, such as Becker Underwood's BioStacked® inoculant, through farmer-based experimentation and adoption of innovative production techniques. Subobjectives included evaluating the effectiveness of biologically stacked inoculants on local and improved germplasm and quantifying genotype by environment interactions and constraints to enhancing BNF of inoculated plants.

Field evaluation of locally adapted and improved bean varieties and inoculants

Uganda

The project had four demonstration sites established on low, medium, and high altitude areas in Uganda. Three common bean varieties were selected by market preference: K132, K131, and a landrace Kanyebwa. Climbing bean varieties at the high altitude site included NABE 10C, NABE 12C, and a landrace. All sites were subject to similar treatments and intensive agronomic management practice. Three inoculant types were used—Biostacked®, Nairobi University's inoculant, and Mak Bio Fixer from Makerere University; a no inoculation was also tested. There were two rates of phosphorus application, 0 and 40 kg ha-1, and the experimental design was split plot. Data collected included plant biomass, yield, seed yield components, leaf area index at flowering, and nodule number per plant.

Field studies were conducted over three growing seasons at three or four locations each season. In general, seed yields on the small research plots in low altitude were greater than typically observed on farmers' fields but far less than the yield potential of the varieties tested. Averaged across varieties, there was no consistent response to inoculant or phosphorous fertilizer at the lowland sites. The combination of inoculant and phosphorus application, however, provided a positive response, but the response was not consistent by variety or inoculant.

The climbing beans tested at the high altitude site responded to phosphorus application in all inoculation treatments. Makerere University inoculant performed well with landrace climbing bean while Nairobi University inoculant performed well with NABE10c and NABE12c climbing beans. Again, the combination inoculant and supplemental phosphorous fertilizer provided the most consistent positive responses.

Tanzania

Field trials were established at mid and low altitudes, from which soil samples were collected and analyzed. The treatments included P application (P+ and P-), four types of Rhizobia applications. Control plots were not inoculated. The response of five locally adapted bean genotypes was tested. Phosphorous application was the main plot, with rhizobia inoculation as subplots and genotypes as subsubplots.

There was considerable variation among genotypes in response to rhizobia inoculant and phosphorous fertilizer.

As observed in the Uganda trials, there was considerable variation among genotypes in response to rhizobia inoculant and phosphorous fertilizer. Bilfa-4 did well both at low soil fertility and in well fertilized soils. It was the only variety tested to have a consistent positive response to the inoculant plus phosphorous treatment.

Two related field trials in 2012 in high altitude tested 16 bean genotypes for their response to inoculant in terms of bean yield and nodulation. Seven genotypes had good nodulating ability, but there was little relationship between nodulation and bean yield. In both field experiments, P had a positive effect on nodule formation regardless of rhizobia inoculation.

The results from field trials in Tanzania confirm that commercial varieties have much greater yield potential than achieved in the field, even under managed research conditions. There were significant location x genotype interactions for all traits measured. Significant interactions were evident for inoculant x genotype and, in some cases, for location x inoculants x genotype for BNF-related traits. Overall, there were numerous observations of a positive impact of inoculation, in most cases when additional phosphorous was provided to support nodulation.

Rwanda

Six adapted climbing, semiclimbing, and bush varieties were evaluated for nodulation and N-fixation using biostacked rhizobia strains from Becker Underwood and the University of Nairobi with or without P and FYM in four districts in Rwanda of known climate and soil characteristics. Results from Cyabayaga in Nyagatare district indicate use of inoculants produced significant differences in dry grain yields, with better response among climbing beans. Results from demonstration trials in Ngoma and Musanze/Burera districts show greater vegetative biomass accumulation in the interaction between native rhizobia strains and farmyard manure or both. At each site, numerous plant phenotypic traits were measured.

As observed at the Uganda and Tanzania test sites, there was a significant interaction between bean variety and the Rh±P± treatment combinations on bean grain yield. (Rh+ = inoculated, P+ = phosphorous fertilizer added). The Rh±P± treatment combinations did not significantly affect bean grain yield in the climbing bean variety MAC 28 and the bush bean varieties RWR 1180 and RWR 2245 but had a significant effect in the climbing bean variety MAC 9, except in the RhMP+ (rhizobium Makerere type inoculated plus phosphate fertilizer applied), which was lower.

The results of the Rwanda field study show that inoculations with the selected rhizobia strains alone and their combination with inorganic P generally had no significant effects on nodulation. There were, however, interactions between phosphate fertilizer, inoculant, (Rh±P± treatment), and variety for increased ($P<0.01$) bean yield.

Primary limitations to BNF and bean yield

The observed variability in bean yield across locations, varieties, and treatments in all three host countries prompted a number of additional investigations to obtain insight into yield limitations and BNF. Reported here are detailed soil analyses, estimates of active soil rhizobia, and harvest populations.

Chemical analysis of soils sampled from field test sites in Rwanda, Tanzania, and Uganda showed several chemical characteristics that could limit nodulation, plant growth, and bean yield. The soils in Rwanda had low pH, were extremely low in Boron, and very high in Mg and Al; the soils in Uganda were very low in N, P, and Boron. It is noteworthy that all soils were low in Boron, which is essential for nodulation. Nitrogen fixation is unlikely to be significant at sites with such extreme soil issues, regardless of seed inoculation.

As noted above, realized yields varied dramatically, in some cases more than five-fold at the same location. In all cases, yields were well below potential values, which were obtained in field studies with the same varieties conducted at an ISU research station (Figure 1). Measurements of plant population density at harvest revealed a linear correlation between bean yield and final plant stand. Evidently, common beans are not able to compensate reproductive load for the loss of plants during the season. The basis for the decrease in plant density is not certain; the quality of farmer saved, market purchased, and certified seed clearly need to be assessed as a limitation on improving BNF and bean yield.

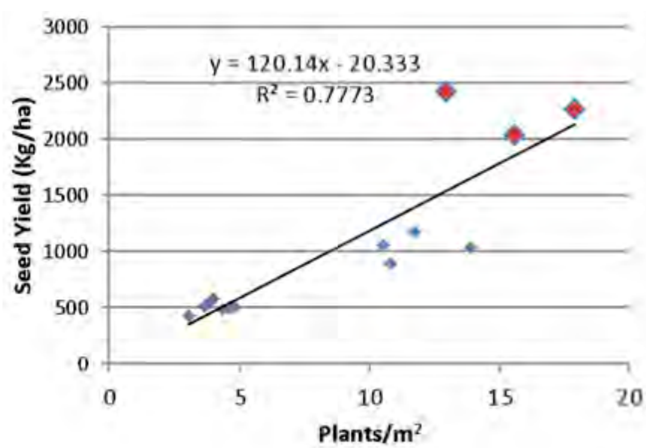


Figure 1. Correlation between bean yield and plant population at harvest. Data are pooled for Kanyebwa and NABE4. Blue symbols are from P-response trials in Uganda. Red symbols are from seed composition studies at ISU. A plant density of 20 plants/m2 is considered optimum for improved bean varieties.

A third potential limitation for nodulation, BNF, and yield is an estimate of the effectiveness of the native rhizobia populations at the field sites. Relative levels of effective rhizobia in soils at field trial locations were assessed by quantifying nodulation response to soil solution inoculation.

Large variation exists in indigenous soil rhizobia levels capable of forming N-fixing nodules, even within Research Station Sites. Variation on farms could be equally dramatic and pose a primary limitation for N-fixation. Variation in host receptivity also could limit N-fixation in locally adapted cultivars. Clearly, these soil chemical and physical limitations must be overcome to resolve the soil biological limitation to BNF.

Examination of inheritance of genetic and environmental variation in BNF

The second strategic aim was to examine the inheritance of genetic and environmental variation in BNF in common bean and to identify molecular markers associated with QTL conditioning for enhanced BNF. Subobjectives focused on identifying parental materials and phenotypic characteristics ideal for inheritance studies of BNF, phenotyping existing mapping populations for BNF response, populating them with molecular markers, and conducting QTL analysis.

Phenotypic and Genomic Evaluation of Bean Lines varying in BNF-related Traits

A population of 100 Recombinant Inbred Lines (RILs) of BAT477 x Dor364, both Mesoamerican bean genotypes, was evaluated for BNF capacity. Bat477 and Dor364 have different root system architectures and contrasting responses to abiotic stress. Bat477 is tolerant to low P soils and Dor364 is drought tolerant. The mean and range values for root and shoot traits are shown in Table 1. The diversity of these progeny lines for such basic phenotypic data (e.g., 17-fold variation in shoot weight) provide the variation needed for an initial QTL analysis with a pre-existing linkage map of SSR and SNP markers.

Variable	Mean	Std Dev	Minimum	Maximum	Fold Difference
root wt. (g)	1.45	0.52	0.29	3.84	13
shoot wt. (g)	3.61	1.28	0.45	8.02	17
% N	2.39	0.36	0.74	3.26	4.4
% S	0.25	0.06	0.16	0.73	4.6
% P	0.32	0.07	0.18	0.66	3.7

Table 1. Traits related to BNF in a greenhouse screen of 100 RILs of BAT 477 x Dor 364 in East Lansing, MI in 2012.

A panel of 284 Andean bean genotypes was SNP genotyped with 533 SNP markers. The data were used to assess diversity, with a clustering of many lines from Tanzania and many of the U.S. cranberry bean germplasm. This information is useful in identifying Andean materials for crossing.

Development of Andean Diversity Panel for phenotypic and genomic analysis

The Andean Diversity Panel was gathered from around the world to assess diversity for economically important traits within the gene pool. It includes 437 accessions from Africa, North and South America, Europe, and India. These accessions include diverse growth habit and seed types as well as landraces and improved lines and cultivars (Figure 2).

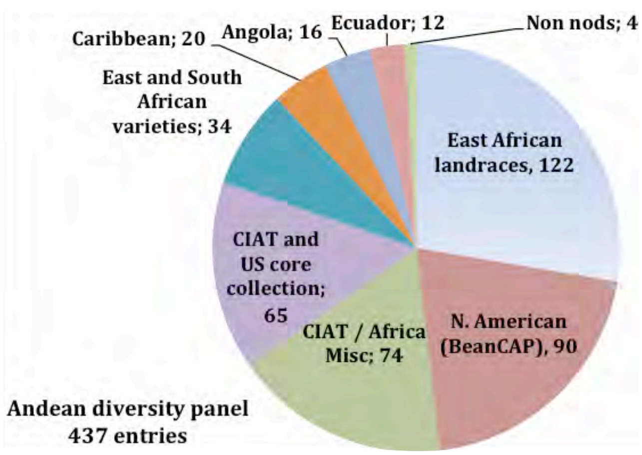


Figure 2. Pie Chart showing distribution of bean lines in the Andean Diversity Panel (ADP) by location of origin.

The genetic diversity of the panel was characterized with 533 Single Nucleotide Polymorphic (SNP) markers and the presence of three major groups within the lines—one Mesoamerican and two Andean. Both Andean groups show some lines with introgression from the Mesoamerican or other Andean group. Since there are diverse preferences for seed sizes, colors, shapes, and plant types, efforts were made to capture this diversity in the panel. Materials from at least eight market classes are represented, including yellow, cranberry, light red kidney, dark red kidney, white kidney, red mottled, purple speckled, and small red.

In terms of plant growth habit, there is a balance in Andean germplasm between bush and vine types. Selection of lines for the panel was restricted, however, to bush type beans because of the vastly different agronomic practices employed to produce climbing beans. There is also a large diversity in capacity for BNF as evidenced by extensive variability in nodulation, plant N accumulation, and seed yield; 275 lines of the Andean diversity panel were evaluated for BNF capacity. Nodulation was estimated at flowering by digging up three plants per genotype per replication. Some lines were identified with large numbers of nodules but overall the CV for this trait was high (37 percent). The genotypes with the highest nodulation scores were mostly African in origin.

These data have allowed more efficient selection of parental materials for Andean bean improvement. The development and characterization of the ADP also has served as an excellent platform for training scientists. The ADP panel is a developed resource including phenotypic and genotypic data that is shared with the bean research community to maximize impact of the resource.

Physiological characterization of bean lines varying in capacity for BNF

The lack of phenotypic characterization for ureide accumulation in tissues of common beans limits the utility of this physiological trait as a tool to identify lines with superior capacity for BNF. We examined nodulation, ureide, and nitrogen accumulation in leaves, roots, stem, petioles, and pods of four genotypes with widely varying potential for BNF. There was significant variation in ureide accumulation across plant tissues and genotypes. The nodulated lines accumulated more total ureides and had a higher ureide concentration than did the nonnodulated line. The difference in total N accumulation between the nodulated lines and the nonnodulated line indicate the amount of N derived from BNF. The variation in total plant N or N derived from BNF across these lines, however, was not correlated with total ureide content.

There was no consistent relationship between ureide concentration, ureide content, and biomass accumulation across leaves, stems, petioles, pods, and roots for the four bean lines examined. Stems consistently showed the highest ureide concentrations, biomass accumulation, ureide content, and total N. The combination of ureide data from stems and leaves could provide the information needed for selecting varieties with improved capacity for BNF.

We used a common grafting technique to determine shoot and/or root control of ureide accumulation and ureide partitioning in the same four genotypes. This research confirmed control of nodulation extent by a translocatable signal from the shoot. Importantly, the results show the potential of increasing nodule number (and ureide accumulation) on a low-nodulator by altering the nodulation signal from the shoot.

Improve Productivity, Profitability, and Sustainability

The third strategic aim was to improve the productivity, profitability, and sustainability of agricultural systems on degraded soils through effective dissemination of new information and technologies to smallholder farmers. Subobjectives included improving farmer awareness of inoculation technologies, conducting on-farm demonstrations of inoculant strategies, and strengthening farmers' collective capabilities to purchase inoculants and incorporate them into a profitable and sustainable system.

- About 80 students per year were trained in BNF technology at Namulonge Research Station.
- About 120 diploma students were trained in BNF technology at Namulonge station.
- In Uganda, 68 farmers were trained and demonstrations of BNF technology established on farm.
- Overall 24 technicians and 145 farmers were trained in a gender balanced way through demonstrations, field days, and organized workshops. About 20 MT seed of farmer preferred varieties were distributed to more than 2,000 household, together with about six kg of inoculants, one MT of DAP, and about 580 MT of FYM in mother–baby demos.
- In the course of the project, 25 field agronomists and RAB technicians were trained as ToTs. In all 150 farmers were trained; 65 percent of these were females.

POTENTIAL DEVELOPMENTAL OUTCOMES AND BENEFITS TO PULSE VALUE CHAIN(S)

- Improve bean productivity contributes to income and food security of smallholder farmers.
- Improved on-farm productivity enhances marketing opportunities for farmer associations.
- Advancing inoculant technology for legumes promotes agricultural enterprise associated with inoculant production and sales.

- New knowledge on bean germplasm x inoculant x environment interactions to inform ongoing variety development programs in the United States and host countries about specific improvements in BNF needed to realize enhanced yield, nutritional value, and marketability of dry beans and other pulses.
- Improving the productivity of common beans particularly helps women.
- Makerere University, National Crops Research Resources Institute (NaCRRI), Namulonge, and VEDCO trained farmers in the Kamuli district on BNF technology.
- The project succeeded in promotion of seed of the climbing and bush bean varieties that were envisaged as best respondents to inoculation and fertilizers.
- The concept and initial development of the Andean Diversity Panel, which represents an association mapping population for genomic wide association studies for identification of genes and QTL influencing BNF efficiency, yield under stress, and other traits important to smallholder farmers.

CONTRIBUTIONS TO INSTITUTIONAL CAPACITY BUILDING

Graduate and undergraduate training with world-class scientists has been central to this project. Capacity building included formal education for seven M.S.-level graduate students and five undergraduate students from host countries.

Capacity building in terms of nondegree training included formal internships for five undergraduate students and training of HC laboratory technicians, field agronomists, and extension staff on the use and agricultural benefits of seed inoculants. Three undergraduate students were assigned to the field sites in Rwanda to assist in germplasm evaluation. Two undergraduate interns were assigned to work on information dissemination.

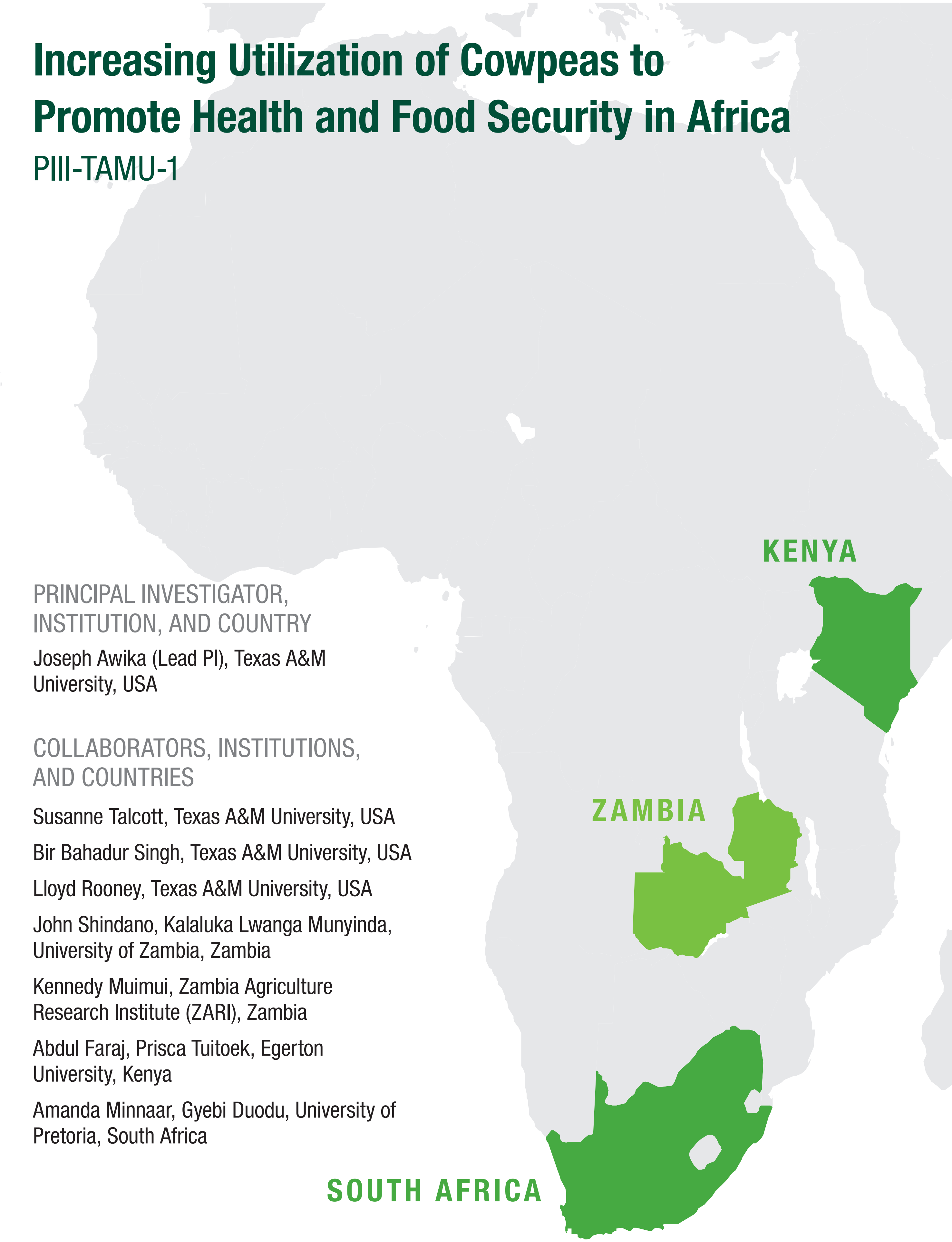
Four undergraduate students (50 percent women) were attached for field training in the Nyagatare ISAR station. They participated in the laying of trials and demonstrations and were involved in the training of farmers and the organization of field days and other awareness and education activities. They also produced a training report.

KEY PUBLICATIONS

Tuyiringire, Justin, Nyiramugisha, Josiane and Nyiratamba, Alice. 2012. Effect of rhizobial inoculation and phosphorous on nodulation and yield of bush and climbing beans in Rwanda. *Training report on inoculations of beans, management, field, statistical techniques and benefits to smallholder farmers in Rwanda*. Dry Grain Pulses Collaborative Research Support Program.

Increasing Utilization of Cowpeas to Promote Health and Food Security in Africa

PIII-TAMU-1



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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

Cowpea is a vitally important crop for food and nutritional security, income generation, and cropping system sustainability in many drought prone regions of Africa. Unfortunately, beyond providing basic nutrition, little is known about the potential of cowpea to contribute to the health of the poor. The widening nutritional paradox in Africa, with high incidences of malnutrition and compromised immune systems among the rural poor and growing incidences of obesity and chronic disease in urban areas, necessitated a search for solutions that sustainably contribute to nutritional security and improved health. Cowpea has tremendous potential as a dual purpose crop, providing essential protein and micronutrients while promoting health and reducing chronic disease risk in sub-Saharan Africa.

These cowpea varieties, if consumed regularly, could be exploited to strategically boost the immune system of children and fight chronic health conditions in adults

This project aimed to discover the 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 composition. In general, light brown cowpea lines had the highest tannin content while red lines had the most flavonols. Only black and green cowpea lines had anthocyanin pigments. High tannin composition correlated with the strongest oxidative stress inhibition; high flavonol and anthocyanin composition correlated strongly with prevention of chronic inflammation. The cowpea varieties most commonly grown in East and Southern Africa, red and light brown, had the strongest bioactive properties. Cooking as well as simulated gastric digestion did not negatively impact measured bioactivity.

These cowpea varieties, if consumed regularly, could be exploited to strategically boost the immune system of children and fight chronic health conditions in adults. Additionally, the majority of cowpea tannins are low molecular weight forms that are not likely to interfere with the bioavailability of such essential micronutrients as zinc and iron. These findings provided the foundation for additional investigations to uncover the physiological mechanisms by which cowpea-based foods and diets might improve human health. Thus, red and light brown cowpea lines that have been improved to have high protein (more than 32 percent), iron, and zinc will be made available for field testing in Africa.

PROBLEM STATEMENT AND RESEARCH APPROACH

Poor families in sub-Saharan Africa suffer high rates of malnutrition, especially among children, while diet-related chronic diseases have become a common phenomenon among urban African populations. A recent survey reported that stunting and overweight due to malnutrition coexisted and were rampant among school-age children in poor communities of Western Kenya. Moreover, evidence indicates that childhood malnutrition is linked to depressed immunity and may lead to increased risk of chronic diseases, such as cancer, in adulthood. Further, nutrition-related chronic diseases are becoming increasingly common in Africa, putting a large strain on the limited health infrastructure and imposing economic burdens on the poor.

Research shows that regular consumption of dry beans and other legumes may reduce serum cholesterol, improve diabetic therapy, and provide metabolic benefits that aid in weight control as well as reduce the risk for coronary heart disease and cancer.

In Africa, malnutrition is closely linked to food insecurity; the most vulnerable groups live in marginal rainfall rural areas and among the urban poor. Cowpea is one of the most drought tolerant crops, has high quality proteins, and has demonstrated high antioxidant capacities that may be improved by heat processing or fermentation. Recent evidence also suggests that whole cowpea is effective at binding cholesterol and lowering blood cholesterol in hamsters. However, information on how cowpea and its constituents may directly impact human health is lacking, as is how variations in cowpea genetics affect their composition of potentially beneficial compounds, making it difficult to promote cowpea as a healthy grain, which dampens its demand and utilization.

The image of cowpea as a healthy food lags behind other commodities, partly due to lack of scientific data on its health and nutritional benefits and partly due to its image as poor man's food. These ideas leads to weak demand and depressed economic value of the crop that in turn leads to limited incentive to invest in efficient cowpea production and utilization infrastructure.

Reliable scientific evidence is essential to make educated dietary recommendations on type of cowpea, level of consumption, and design of food processing strategies that maximize the beneficial effects. The evidence will also provide a basis for genetic and agronomic improvement aimed at optimizing composition of beneficial compounds

Identify cowpea lines with high content of health enhancing compounds and their relationship to seed coat color and other seed traits

The goal was to determine genetic variability in cowpeas for the types and levels of key bioactive components as well as protein content and quality. More than 110 cowpea lines of diverse phenotypes from West Africa, East and Southern Africa, and the United States were screened for bioactive composition. Association between these traits and seed color and seed characteristics was determined.

Gross phenolic composition

Samples were ground into flour and phenol content (Folin-Ciocalteu), anthocyanin pigment content (pH-differential), and tannin content (vanillin-HCl) were measured. From these analyses, samples were grouped into six phenotypes based on seed coat color: black, red, light brown, golden brown, streaked (mixed colors), and white. Two representative samples within each phenotype were selected for use in detailed chemical characterization and biochemical assays.

Flavonoid profiling

Flavonoid profiling was used to determine the structural composition of various phenolic compounds in cowpea to provide a foundation for interpreting bioactivity data since polyphenol structure has a major impact on its biological activity.

Protein content and quality

Protein content and available lysine were measured; protein content, quality, and amino acid profiling were also done on selected samples that were subjected to micronization, an infrared heat treatment intended to reduce the cooking time.

Establish how the phytochemical profiles of cowpeas affect bioactivity by measuring key markers/predictors of protection against chronic diseases

The goal was to establish how phytochemical profiles affect the ability of cowpeas to influence metabolic, inflammatory, and chemoprotective health predictors in vitro. In addition to standard organic solvent extraction procedures, enzymic digestion (simulating gastrointestinal conditions) of cooked cowpea samples was performed to better mimic what would happen in humans. The enzyme digests were compared to extracts obtained using standard procedures based on organic solvents.

Antioxidant activity

Hydroxyl/free radical scavenging properties.

Protection against oxidative stress is an important component of chronic disease prevention. Antioxidant capacity of cowpeas and their fractions was measured. The ability of cowpea extract to protect fluorescein from free radical attack by AAPH was monitored for 90 min at 37°C.

Inhibition of low density lipoprotein (LDL) oxidation.

Oxidation of LDL leads to impairment in the regulation of cholesterol uptake, which potentially leads to the development of artherosclerosis and cardiovascular disease. The ability of extracts from the cowpea varieties to inhibit LDL oxidation was determined by monitoring formation of conjugated dienes at 234 nm.

Cell culture assays

Two strategies were used to assess how cowpea compounds can protect against cancer and chronic inflammation in the gut.

Anticancer effects

- *Phase II detoxifying enzyme assay.* This method is based on the fact that enhanced activity of enzymes that detoxify potential carcinogens will lead to prevention of cancer initiation. We used the NAD(P)H:quinone oxidoreductase (NQO) inducer activity in murine hepatoma (Hepa 1c1c7) cells as the indicator for phase II enzyme activation. Sulforaphane was used as a positive control; this compound is a potent natural phase II enzyme inducer.
- *Antiproliferation assays*. These methods measured how the various cowpea extracts affect growth of preformed cancer cells and are useful in predicting the potential protective effect of cowpea against preformed cancer in early stages.

Inflammation and oxidative stress

The *in vitro* effects of cowpea phenolic extracts and fractions from cowpea on biomarkers for antioxidant properties and inflammation were measured using human colonic myofibroblasts (CCD-18co) as the cell model. These nonmalignant cells are a good model for estimating the potential protective effect of beneficial compounds in colon epithelium and, thus, gut health.

Biomarkers for inflammation. Nuclear factor kappa B (NFκ-B), interleukins IL-6, IL-8, tumor necrosis factor TNF–α, and Nf-κB was determined by ELISA assays. These biomarkers are typically used to assess inflammation; the ability of cowpea extracts to decrease LPS-induced inflammation in these cells was measured.

Antioxidant biomarkers. Cells were treated with different cowpea extract concentrations and the antioxidant effects were determined after different incubation times. Additionally, oxidative stress was induced with hydrogen peroxide and the mitigation of pro-oxidant potential by different concentrations of cowpea extract was assessed. Oxidative DNA damage was assessed in the same manner; after the induction of DNA-damage with H_2O_2, the alleviating effects of cowpea extracts were assessed with the ApoAlertTM DNA Fragmentation Assay (BD Biosciences).

Elucidate the mode of heritability of selected bioactive traits in cowpea and the genetic association between physical and bioactive traits

This objective aimed to determine the mode of inheritance and the extent of genetic associations of key bioactive traits in cowpea, which will open opportunities for genetic selection and improvement efforts as well as using modern molecular techniques to develop specific specialty cowpea lines for targeted health benefits.

Crosses

Greenhouse experiments were conducted to study the inheritance of antioxidant activity in cowpea. A number of crosses were made between 10 different parents selected based on their polyphenol content/antioxidant activity as low parent with high parent. The successful crosses were:

- Early Acre (low antioxidant) x IT82D-889 (high antioxidant)
- TX 2028-1-3-1 (low antioxidant) x 1042-3 (high antioxidant)
- IT98K-205-8 (low antioxidant) x IT97K-1042-3 (high antioxidant)
- GEC (low antioxidant) x IT97K-1042-3 (high antioxidant)
- Bambey- 21 (low antioxidant) x IT97K-556-4 (high antioxidant)
- CB-27 (low antioxidant) x IT97K-556-4 (high antioxidant)
- Bambey -21 (low antioxidant) x TVu 7777-8 (high antioxidant)

The resulting F1 seeds were grown in the greenhouse, and F2 populations were generated for most of the crosses. In view of the significant association between seed color and antioxidant content, notes were also taken on seed phenotypic traits in F1 and subsequent generations. Various combinations of seed colors were observed in F2 and F3 seeds, including complementary gene action for seed color in some crosses.

ACHIEVEMENTS AND OUTPUTS

Cowpea phenolic composition and diversity

- There was a very broad variability in phenol content of the cowpea lines, with values ranging from 0.30 – 17 mg/g seed (dry basis), based on the Folin-Ciocalteu method with gallic acid as the standard (Table 1). This represents more than a 50-fold variability in phenol content of cowpea, which underscores the need for a clear understanding of how the cowpea genetics and phenotypes influence accumulation of the phenolic compounds.

Seed coat color	Gross phenol content (mg/g, db)		Condensed tannin content (mg/g, db)		N
	Range	Mean	Range	Mean	
White	0.30 – 5.5	3.1 a	0.29 – 1.3	0.59 a	36
Light brown	5.7 – 16.5	12.0 c	8.8 – 12.3	10.4 d	21
Dark brown	5.2 – 9.0	6.8 b	1.9 – 6.7	3.6 b	8
Streaked	5.4 – 9.9	8.5 b	3.6 – 3.8	3.7 b	5
Red	10.1 – 14.2	11.9 c	4.8 – 7.8	7.3 c	5
Black	12.5 – 17.0	14.8 cd	6.3 - 9.0	7.7 c	3

Table 1: Phenol and tannin content of cowpea varieties grouped by seed coat color.

N represents the number of varieties analyzed within a phenotype. Coefficient of variability for phenol content determination was 3.1% and for condensed tannins was 4.4%. Values with same letters in a column are not significantly different ($p < 0.05$).

- When the samples were grouped based on seed coat color, significant patterns were observed, as specified in Figure 1. These finding underscored the need to identify the specific compounds contributing to the high phenol content in the cowpea.
- The cowpea polyphenols were more than 98 percent concentrated in the seed coat; the cotyledons contained trivial amounts of these compounds. Among the major functions of phenolic compounds in the seed is protection against pathogens and pests; thus, it makes sense that the plant would concentrate synthesis of these compounds in the protective seed coat. This finding is especially

important in advising on food processing strategies that should be employed to limit the loss of the potentially bioactive compounds. For example, dehulling cowpea is not recommended if health benefits of polyphenols are to be realized.



Major flavonoid	Red	Cream (light brown)	Black	Golden brown	Green	White
Flavan-3-ols	High	Highest	Mod	High	-	-
Flavonols	Highest	Low	low	Mod	Low	Low
Anthocyanins	-	-	Highest	-	Low	-



Figure 1. Major groupings of cowpea based on seed coat color and pattern of flavonoid composition in each phenotype. Sample classification from top, clockwise: red, golden brown, light brown, white, rgeen, and black.

- We structurally identified more than 70 phenolic compounds in diverse cowpea varieties, most of them for the first time. The dominant compounds in most cowpea varieties were various derivatives (glycosides, acyl glycosides, etc.) of quercetin (a flavonol) and catechin and afzelechin (flavan-3-ols). Even though most lines investigated had a mix of the compounds identified, important patterns were observed (see Fig 1). For example, anthocyanins were exclusively found in black and green varieties, whereas the white and green varieties had no flavan-3-ols. The dominant flavonoids in major cowpea phenotypes (seed coat color) can be summarized as follows:
    - Light brown – flavan-3-ols (catechin and condensed tannin family)
    - Red – flavonols (quercetin family)
    - Black – anthocyanins (pigment family)
    - White – flavonols (with no tannins)
- Interestingly, unusual composition of tannins was observed in cowpea; glycosides of monomeric flavan-3-ols were the largest group of tannins (36 to 69 percent) in cowpea with oligomeric forms accounting for 15 to 20 percent and polymers accounting for only 13.5 percent. Given that the high molecular weight tannins are the ones that bind most strongly to protein and micronutrients, thus reducing their bioavailability, the composition of cowpea tannins is advantageous from a nutrient bioavailability perspective
- The polyphenol composition information is especially important because the specific bioactive properties of the polyphenols are determined by their structure, and the information is useful in selecting specific cowpea phenotypes and cultivars to process “smart,” healthy foods that target specific health benefits. The information is also useful in genetic improvement for desirable phenolic profile in cowpea.

Cowpea bioactive properties measured using *in vitro* models

- Free radical scavenging activity of cowpea extracts generally correlated with their phenol content, which confirms that the polyphenols in cowpea are the major determinants of their antioxidant activity.
- Cowpea extracts were tested for their potential for cancer prevention by determining their effect on proliferation of HT-29 and Caco-2 human colon carcinoma cells, induction of phase II detoxifying enzymes in murine hepatoma (Hepa 1c1c7) cells, and inhibition of oxidative DNA

damage. The cowpea extracts decreased proliferation of the cancer cell lines and induced phase II enzymes in Hepa1c1c7 cells. The extracts also showed significant inhibition of oxidative DNA damage.

- Cowpea extracts were also tested for anti-inflammatory properties and potential for cardiovascular disease prevention by determining their effect on cellular processes and gene expression in HUVEC and CCD-18co cells and inhibition of LDL oxidation. The extracts reduced production of reactive oxygen species, expression of inflammation biomarkers in the cells, and inhibited LDL oxidation, which indicates ability to prevent chronic inflammation in the gastrointestinal tract and cardiovascular disease.
- In general, most cowpea lines tested had good anti-inflammatory properties at low concentrations of two µg extract/mL; thus, they may lower the risk of chronic inflammatory conditions at levels encountered in normal dietary consumption. Varieties containing higher levels of flavan-3-ols (tannins) were generally least effective in reducing VCAM-1 and NF-κB gene expression compared to varieties containing higher levels of anthocyanins and flavonols suggesting lower anti-inflammatory properties. Conversely, the high flavan-3-ol varieties were most effective at reducing oxidative, stress-induced cell damage. This evidence suggests cowpea phenolic composition may influence specific biochemical pathways relevant to chronic disease prevention.
- *In vitro* digestion of cowpea increased the efficacy of the extracts since they were active at reducing the inflammatory markers at a lower concentration than comparable organic solvent-based extracts (Fig 2). Therefore, digestion of cowpea will not negatively impact the effect of the antioxidative compounds in reducing the expression of the pro-inflammatory molecules that help reduce inflammation, decreasing the incidence of cardiovascular disease.

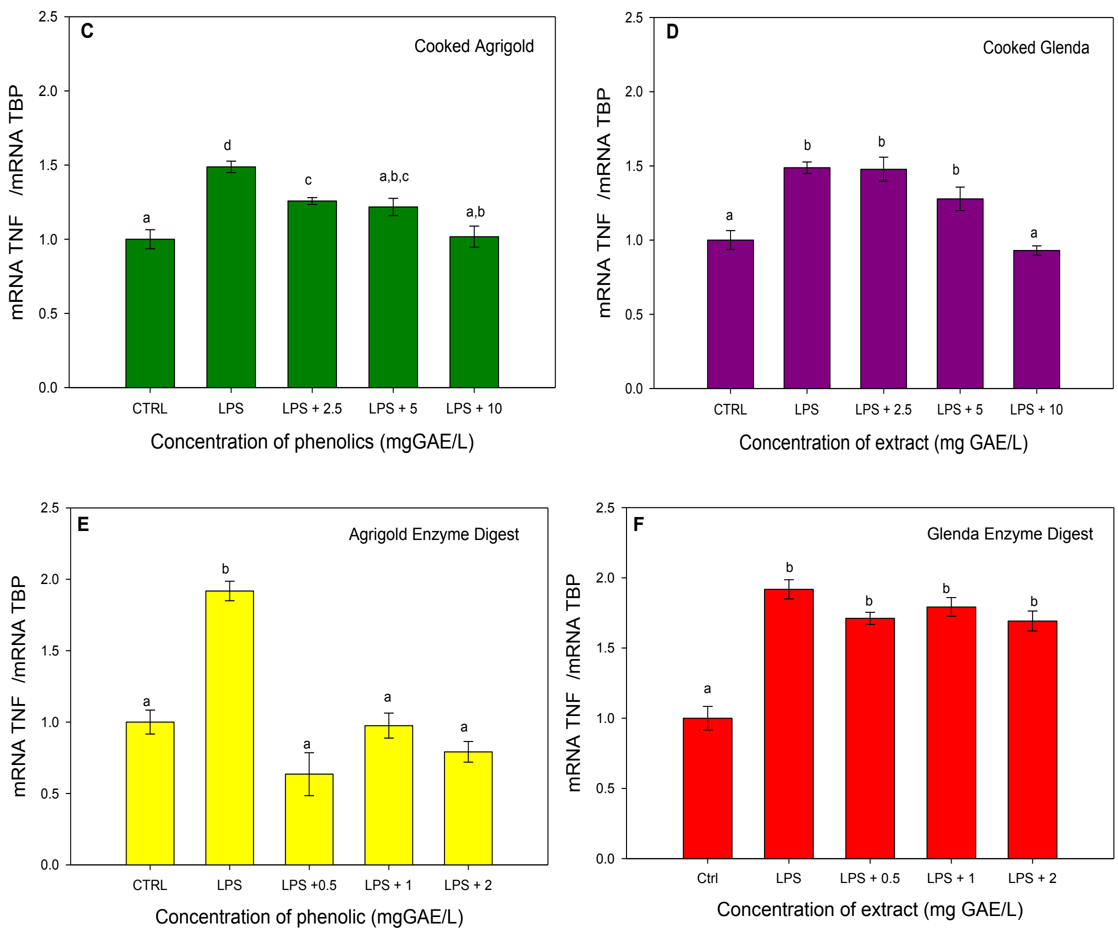

Figure 2. Effect of cooked cowpea extracts from two African varieties on the gene expression of tumor necrosis factor (TNF) α by Human umbilical vein endothelial cells. Cells were pre-treated for 24 hrs with different concentrations of extracts from raw, cooked and enzyme digested Agrigold and Glenda cowpea types, then stimulated with LPS (1µg/mL) for 4hrs. mRNA was extracted, reverse transcribed and amplified by RT-qPCR using specific primers for TNFα and expressed as a ratio to TBP mRNA. Values are means ± SE (n = 6). Different letters indicate a significant difference at $p < 0.05$.

- The anti-inflammatory and antiproliferative effects of cowpea polyphenolic extracts on human endothelial and epithelial cells in vitro was most likely synergistic, owing to the diversity of structurally related flavonoid compounds in cowpeas.

Some light brown varieties accumulated mostly tannins while other varieties accumulated mostly flavonols.

The results of this research show the important role cowpeas can potentially play in combating chronic diseases of lifestyle, such as cancer and cardiovascular disease.

These results indicate that in addition to their traditional role of preventing protein malnutrition, stunting and wasting, intake of cowpea may have greater potential in managing and/or preventing degenerative diseases associated with oxidative damage and chronic inflammation. This information could increase public recognition of the health benefits of consuming specific cowpea phenotypes, which could increase the demand for food uses of cowpea and other legume seeds.

Inheritance (heritability) of selected bioactive traits in cowpea and genetic association between physical and bioactive traits

- The goal is to open opportunities for genetic selection and improvement to develop specific cowpea lines for targeted health benefits. This would be a form of biofortification of cowpeas to enhance their ability to contribute to chronic disease prevention.
- In general, preliminary investigation reveals that seed coat color and texture (rough vs. smooth) are reliable indicators of phenol content and antioxidant activity, thus heritability of these seed coat traits explains most of variability in bioactive content of the seed. Within the same color group, smooth seed coat cowpea varieties will have higher phenol content.
- Within a given seed coat color, polyphenol composition (the type of polyphenols accumulated) varied significantly. Some light brown varieties accumulated mostly tannins while other varieties accumulated mostly flavonols. This variability appeared to be rather complex, with multiple genes interacting in ways that could not be fully inferred within the project period. Additional data would need to be collected, because we observed important differences in anti-inflammatory and antioxidant properties based on polyphenol composition, which imply important role of polyphenol composition on health benefits of cowpea.

Figure 3. Parents (Bambey 21 and IT97K-556-4) and F1 hybrid or F2 seeds suggesting a complementary gene action for black seed coat color. Black seed coat color denotes accumulation of anthocyanin pigments.

- When Bambey 21 (white, no eye) and IT97K- 556-4 (light brown, no eye) cowpea varieties were crossed, the F1 plants produced black seeds, suggesting a complementary gene action for seed coat color (see fig. 3). Chemical analysis showed complete absence of anthocyanins in both parents but very high levels in the hybrid, indicating gene complementation for anthocyanin accumulation. In addition, hybrid vigor in flavonol content was observed in the hybrid, where accumulation of quercetin derivatives increased by more than two-fold compared to parental mean.
- Even though it is apparent that heritability of seed coat color in cowpea is complex, that the color itself is a good indicator of the type of flavonoid compounds accumulated by the seed may be more important because our findings demonstrate that the type of flavonoids present in cowpea seed coat correlate with indicators of specific bioactive properties.

POTENTIAL DEVELOPMENTAL OUTCOMES AND BENEFITS TO PULSE VALUE CHAIN

- Marketing of high nutritional quality cowpea with demonstrated health benefits will generate income to the small-scale producers and processors (a large part of who are women).
- Consumers will have a greater choice of superior nutritional quality products. The overall long-term health of the population will improve, reducing overall health care costs and disease burdens among vulnerable groups.
- Demonstrated health benefits will stimulate development of new cowpea varieties and food products that offer variety, convenience, and cost benefit to consumers.

- Improved agricultural production is a key factor in sustainable economic development. Genetic technology with increased yield, stress resistance, and quality of cowpea grown in an environmentally nondisruptive integrated cropping system will increase on-farm food availability while providing a greater and more reliable supply of plant products for off-farm sale.
- Human capital development is the key factor to improve host country institutional research capability and sustainable agricultural development.
- The creation of designer cowpeas for health benefits will gain new markets for health conscious consumers. With accurate scientific information, hybrids that target specific health benefits can be developed and marketed to health food subsectors. This will also stimulate research in processing methods to enhance product diversity and consumer acceptance.

CONTRIBUTIONS TO INSTITUTIONAL CAPACITY BUILDING

Four graduate students (three Ph.D., one M.S.; three females and one male) from Zambia and Kenya have been trained through this project, and two Ph.D. students have benefited indirectly from the project.

Short-term training was provided to 87 personnel in Zambia and Kenya on various aspects of the project. The trainings were conducted via three workshops, two in Zambia and one in Kenya.

KEY PUBLICATIONS

Kayitesi, E.; Duodu, K. G.; Minnaar, A.; de Kock, H. L., Effect of micronisation of pre-conditioned cowpeas on cooking time and sensory properties of cooked cowpeas. *Journal of the Science of Food and Agriculture* 2013, 93:838–845.

Ojwang, L.O., Susanne Talcott, and Joseph M Awika. 2011. Anti-inflammatory properties of cowpea phenotypes with different phenolic profiles. [Best Student Research Paper Competition (1st PLACE WINNER), AACC International, October 2011]. *Cereal Foods World* 56:A3–A4.

Ojwang, L. O.; L. Dykes, J. M. Awika. 2012. Ultra performance liquid chromatography-tandem quadrupole mass spectrometer profiling of anthocyanins and flavonols in cowpea (*Vigna unguiculata*) of varying genotypes. *Journal of Agricultural and Food Chemistry* 60:3735–3744.

Ojwang, L. O.; Yang, L.; Dykes, L.; Awika, J., 2013. Proanthocyanidin profile of cowpea (*Vigna unguiculata*) reveals catechin-*O*-glucoside as the dominant compound. *Food Chemistry* 139:35–43.

Pulse Value Chain Initiative—Zambia (PVCI-Z)

PIII-KSU-1

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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

The Pulse Value Chain Initiative – Zambia (PVCI-Z) provides baseline information about the bean and cowpea value chains in Zambia to facilitate total chain performance, increase producer incomes, and enhance food security among pulse growers in Zambia. Its goal was to develop a better appreciation of pulses in the food security profile of Zambian producers; pulses are a minority crop in Zambia.

Realizing the potential of pulse crops in Zambia requires that they be recognized as a predominantly food security crop, that woman become major producers, and that targeted education on the various nodes in the value chain is implemented, particularly for traders about business and management. The project also celebrates the human capacity it has contributed to developing in a short time. Three master's in agribusiness students graduated this past spring and three of the six undergraduate students who have already graduated received scholarships to continue their education in Europe and South Africa.

PROBLEM STATEMENT AND RESEARCH APPROACH

Although a minor crop within Zambian agriculture, beans and cowpeas have been identified as crops with significant income and food security potential. Pulses have yet to attain prominence in the production portfolio of smallholder Zambian farmers, possibly because of Zambian public policies that provide overwhelming support for maize to the near exclusion of all other crops.

There has been a lot of talk about increasing the role of pulses in Zambian agriculture and food; however, there is little or no knowledge of how smallholder producers perceive pulses in their portfolio. Are they producing pluses principally as a subsistence crop or as a supplementary income crop? Are they producing beans and cowpeas for food security or as a primary income crop? Understanding the role of pulses in the crop portfolio of Zambian farmers would be instrumental in helping develop public policies to support their expansion in producers' portfolios. Additionally, understanding how producers are participating in the market and any challenges they face there could provide insight into addressing these challenges and increasing market participation rates.

Although a minor crop within Zambian agriculture, beans and cowpeas have been identified as crops with significant income and food security potential.

The vision of the Pulse Value Chain Initiative—Zambia (PVCI-Z) to contribute to poverty alleviation and to improve food and nutrition security through research, education, and engagement, was conceived around two principal objectives: to understand pulse producers in Zambia and their perceptions of pulses in their income and food security strategies so as to understand the supply and its challenges and to provide training and capacity development solutions to help improve participants' knowledge of the potential of these crops in contributing to income improvement and food security.

The focus of this research was on smallholder producers of beans and cowpeas in Zambia. The data were collected using a structured questionnaire survey instrument in the principal producing districts in Zambia: Mbala and Lundazi (bean) and Kalomo and Lundazi (cowpeas).

The survey was conducted between November 2011 and February 2012 and resulted in a total of 1,000 usable responses from the study districts as follows: Lundazi, representing Eastern Province (297); Mbala, representing Northern Province (349); and Kalomo, representing Southern Province (354).

ACHIEVEMENTS AND OUTPUTS

The project's achievements are presented according to its objectives. The first part involves baseline information on producers and the second part reports capacity building achievements.

Importance of Pulses for Zambian Smallholder Producers

The results show that nearly all respondents (90.2 percent) indicated farming as their primary occupation. Nearly 68 percent of households grew mixed beans, compared to 52.5 percent who grew cowpeas. Almost all (97 percent) of the households grew maize, Zambia's staple food crop. A little more than 27.0 percent of the survey households were shown to be located in each of Eastern and Southern Provinces, while 45.2 percent resided in Northern Province.

Weighted average cropland was about 8.3 ha with a standard deviation of 6.7 ha and ranged from 0.3 ha to 37.0 ha. The average annual income of the sample was ZMK3.1 million, suggesting that the average income of the sample is significantly lower than the national average income. This measure also provides a benchmark for designing policy since the opportunities embedded in mixed beans and cowpeas are explored to enhance producer incomes and reduce poverty.

The weighted summary statistics of all crops grown by the surveyed households in the 2010/2011 agricultural season provides an indicator of the importance of beans and cowpeas in the crop portfolio of these households. As expected, maize is the most important crop in the household's crop portfolio, receiving an average of 2.6 ha. Mixed beans and cowpeas were the second and third in allocated area, with an average allocation of 2.35 ha and 2.32 ha respectively. This indicates that these crops are very important in these bean- and cowpea-producing districts, competing effectively with maize. Of the total respondents, 612 and 516 reported some allocation of land to beans and cowpeas. Apart from maize, no other crop reported higher participating household numbers.

The importance of beans and cowpeas is further illustrated by the number of households that indicated planting them. While 189 of the sample households planted maize, beans, and cowpeas, only three grew beans and cowpeas to the exclusion of maize. While only three households planted only cowpeas or only maize, about 402 households planted beans and maize but no cowpeas, and 322 planted cowpeas and maize but no beans.

Although only smallholders with less than 40 ha of total cropland are included in the analyses presented in this report, the weighted statistics for cropland show a wide distribution among producers. A larger proportion of cowpea growers (33 percent) had more than three ha but less than six ha of cropland compared to 29 percent of cowpea growers. The analyses show that females had smaller land holdings and lower outputs than males in maize, mixed beans, and cowpeas, ensuring that their production levels were also lower.

The cropland productivity for maize, mixed beans, and cowpeas also shows that females' are lower than males. The average yields by gender shows that there are statistically significant differences between males and females for mixed beans and maize but not cowpeas, suggesting that while beans may be considered a "woman's crop" in other parts of Africa, they are not in Zambia.

Distribution Channels Used by Smallholder Pulse Growers

Of the 538 households that produced mixed bean, about 66 percent sold part or all of their production, suggesting that for 208 households mixed beans production was solely for nonmarket use—home consumption, gifts, and in-kind payment for goods and services. Only 32.7 percent (about 150 households) of cowpea-producing households participated in the market. There were no statistical significant differences between males and females in market participation in both crops.

A number of trading nodes (consumers, retailers, traders, and institutions) determine producers' market entry points. Traders include local and foreign traders; institutions encompass hotels and restaurants, processors, brokers, NGOs, cooperatives and trade associations, schools, universities, hospitals, and government agencies. The results show that 78 mixed bean market participants sold directly to consumers while only 58 and 124 sold directly to retailers and traders. About 129 mixed bean market participants sold directly to institutions. The results are little different for producers participating in the cowpea market.

Table 1 shows that mixed bean market participation by gender was slightly off from this distribution of population by gender.

Table 1. Distribution of Mixed Bean Market Participants by Supply Chain Node and Gender

Nodes	Male (%)	Female (%)	Total (%)	Number of Participants
Consumer	17.3	1.33	18.63	78
Retailers	14.06	3.08	17.14	58
Traders	30.25	2.15	32.4	124
Institutions	33.54	5.55	39.09	129
All Nodes	88.47	11.53	100	364

Table 2 shows that the proportion of male cowpea market participants was about 87.7 percent compared to 12.3 percent for female.

Table 2: Distribution of Cowpea Market Participants by Supply Chain Node and Gender

Nodes	Male (%)	Female (%)	Total (%)	Number of Participants
Consumer	32.46	1.13	33.59	57
Retailers	10.22	4.851	15.07	22
Traders	40.12	5.142	45.26	66
Institutions	8.68	1.628	10.31	14
All Nodes	87.68	12.32	100	154

What characteristics of market-participating producers determine where they operate in the chain? Using a logit model, where selling to a particular node is defined as 1 and 0 if otherwise, the results for mixed beans show that a percentage increase in the share of land allocated to beans increased the probability of selling to consumers by 23 percent, while a percentage increase in total cropland decreased that probability by 53 percent. Being located in Northern Province instead of Eastern Province increased the probability of selling to consumers by about 29 percent. Selling to traders was influenced by share of land allocated to beans, gender, and living in Southern Province instead of Eastern Province. Being a female producer reduced the probability of selling to traders by 13 percent, while a percentage increase in bean share of total cropland increased the probability of selling to traders by 23 percent. These probability changes are all significant at the five percent or one percent level.

These identified characteristics influence the decision to participate or not participate in the market in various ways. Gender was a factor for mixed beans—but not for cowpeas—with females having a five percent lower probability of market participation. Even a percent increase of crop share on total land use resulted in 18 percent and 19 percent increases in the probability of participating in the mixed bean and cowpea markets, respectively. Most households in Southern Province produce cowpeas for consumption and other nonmarket activities relative to Eastern Province. Market participation for cowpea producers in Northern Province was about 104 percent lower than in Eastern Province. Contrarily, living in Northern Province instead of Eastern Province increased market participation for beans by 18 percent.

Value of Pulse Production for Smallholder Producers

Beans and cowpeas are produced in Zambia for more than dry grain, e.g., bean young leaves, green pods, and fresh bean grains are used as vegetables, which contributes to alleviating food insecurity prior to harvest. These foods are also excellent sources of iron and zinc micronutrients; the same is true of cowpeas. Little knowledge exists, however, on the effect of leaf harvesting on grain yields, and hence, the profitability of cowpea (and similar) production systems. Some households harvest the stover for animal feed or for fuel while the pods may be used as animal feed, fertilizer, and/or fuel. Estimating the value of these crops solely on the dry grain may be underestimating their household value.

To ascertain some semblance of the full value of the crops, survey respondents were asked to indicate the proportion of each product type from each crop that was consumed, given away as gift, used as animal feed, and sold. About 67 percent of respondents indicated consuming more than 25 percent of bean leaves harvested—similar to dry mixed bean grain, for which 54 percent indicated consuming more than 25 percent of the crop. Indeed, 20.9 percent of them indicated consuming all the dry bean grain they produced while only 7.8 percent said they did not consume any of their dry mixed bean grain. About 76 percent of respondents indicated consuming 75 percent or more fresh green beans harvested compared to 23.7 percent who indicated consuming up to 25 percent. This would suggest the food security importance of mixed bean leaves, fresh green beans, and dry mixed bean grain to the smallholder farming households in Zambia. A similar distribution was found for cowpea products that were consumed; however, of the two corps, mixed beans is somewhat more commercially oriented than cowpeas.

On average, total nonpecuniary value accounted for about 58.3 percent and 75.7 percent of total value from mixed beans and cowpea production in the three Zambian provinces.

The role and uses of the various components of beans and cowpeas in these production communities underscore the importance of estimating their value as the sum of pecuniary and nonpecuniary benefits from the whole crop. The average revenue for dry mixed bean was about ZMK578,470. Revenue from fresh grain was about ZMK36,000. The largest single source of revenues for cowpea products was dry grain, with its weighted average revenue approximately ZMK172,000. Fresh and dried cowpea leaves revenue, averaging about ZMK35,000 and ZMK41,000 respectively, provided more revenues for cowpea producers on average than did fresh cowpea grain. This may be because cowpea leaves are deemed to have more nutritional value and are used more as a vegetable.

The summary weighted statistics of the total pecuniary value for the two crops are presented in Table 3 by province and gender. Table 4 also presents the weighted summary statistics of pecuniary value from mixed beans and cowpea production by gender and region. It is predicted that as the pecuniary value from cowpeas increases—as the economic viability of cowpeas are proven in that province as it has been proven in Southern Province—males will enter the market and overtake the females.

Table 3. Summary Weighted Statistics of Total Pecuniary Value by Gender and Province

Type	Variable	N	Weight	Mean	Std. Dev.	Min	Max
Overall	Mixed Beans	526	43,717	470,206	895,819	2,500	8,900,000
Overall	Cowpea	364	23,886	133,128	388,512	2,000	8,100,000
Total Female	Mixed Beans	63	5,284	266,991	458,513	10,000	2,700,000
Total Male	Mixed Beans	462	38,371	498,702	937,707	2,500	8,900,000
Total Female	Cowpea	45	3,222	116,949	300,060	2,000	1,803,000
Total Male	Cowpea	318	20,603	135,347	401,465	2,000	8,100,000
Eastern							
Female	Mixed Beans	21	1,468	238,404	539,345	10,000	2,700,000
Male	Mixed Beans	165	10,842	234,835	402,177	5,000	3,540,000
Female	Cowpea	27	1,817	142,581	297,641	10,000	1,683,000
Male	Cowpea	177	11,663	140,139	469,431	5,000	8,100,000
Northern							
Female	Mixed Beans	41	3,757	270,985	428,559	10,000	1,900,000
Male	Mixed Beans	259	25,313	637,793	1,093,667	2,500	8,900,000
Female	Cowpea	5	420	215,702	584,605	8,000	1,803,000
Male	Cowpea	13	1,378	97,014	161,346	10,000	600,000
Southern							
Female	Mixed Beans	1	59	720,000		720,000	720,000
Male	Mixed Beans	38	2,217	200,988	386,687	5,000	2,900,000
Female	Cowpea	13	985	27,579	28,003	2,000	110,000
Male	Cowpea	128	7,562	134,939	309,606	2,000	2,445,000

In estimating the nonpecuniary value of production, the average of prices received at all nodes in the supply chain for all producers in the sample is used as the imputed price in cases where the household was not a market participant. Where the household was a market participant, the maximum price received from any node is used as the imputed price for nontraded products.

The minimum of total female nonpecuniary value for mixed beans was about seven times that of males while the minimum for cowpeas was the same for both. However, the maximum nonpecuniary value for cowpeas for males was about 20 times than of females. For both crops, the total nonpecuniary value for males was higher in Eastern Province and Southern Province. However, in the Northern Province, weighted average mixed beans' nonpecuniary value was higher for females. Compared to the total average pecuniary value, the number of smallholder households reporting nonpecuniary values for both crops and both genders and in all regions was higher. These participation numbers confirm the importance of not ignoring nonpecuniary value in assessing value of production among smallholder producers.

Finally, the summary statistics of total value to smallholder households producing cowpeas in the three major beans and cowpea producing provinces in Zambia are presented in Table 5.

On average, total nonpecuniary value accounted for about 58.3 percent and 75.7 percent of total value from mixed beans and cowpea production in the three Zambian provinces. The weighted average share of nonpecuniary value of cowpea production was above the overall average, coming in at 88.4 percent for males and 81.7 percent for females.

Table 4. Summary Weighted Statistics of Total Nonpecuniary Value by Gender and Province

Type	Variable	N	Weight	Mean	Std. Dev.	Min	Max
Overall	Mixed Beans	527	42,464	331,183	465,896	1,704	3,901,324
Overall	Cowpea	432	28,943	224,840	875,599	3,056	10,700,000
Total Female	Mixed Beans	67	5,382	365,422	500,558	12,500	2,800,000
Total Male	Mixed Beans	460	37,082	326,214	461,015	1,704	3,901,324
Total Female	Cowpea	59	4,226	125,816	126,923	3,056	518,875
Total Male	Cowpea	372	24,656	242,345	946,295	3,056	10,700,000
Eastern							
Female	Mixed Beans	22	1,617	207,323	216,983	12,500	975,331
Male	Mixed Beans	141	9,275	241,394	372,399	7,000	2,203,526
Female	Cowpea	25	1,735	114,173	116,972	7,500	518,875
Male	Cowpea	129	8,623	366,451	1,409,006	7,500	10,700,000
Northern							
Female	Mixed Beans	36	3,257	460,412	604,851	19,565	2,800,000
Male	Mixed Beans	240	23,477	358,338	473,191	1,704	3,237,500
Female	Cowpea	8	565	102,746	106,693	12,972	319,973
Male	Cowpea	56	5,253	160,906	881,586	4,500	10,700,000
Southern							
Female	Mixed Beans	9	508	259,442	218,781	16,617	675,000
Male	Mixed Beans	79	4,331	333,725	543,068	15,000	3,901,324
Female	Cowpea	26	1,926	143,072	142,106	3,056	518,875
Male	Cowpea	187	10,781	182,759	276,201	3,056	2,594,376

Table 5. Summary Weighted Statistics of Total Value by Gender and Province

Type	Variable	N	Weight	Mean	Std. Dev.	Min	Max
Overall	Mixed Beans	570	46,146	688,143	1,058,325	8,128	9,650,000
Overall	Cowpea	470	31,799	248,385	886,887	3,056	10,700,000
Total Female	Mixed Beans	75	6,105	643,960	1,048,658	16,617	6,000,000
Total Male	Mixed Beans	495	40,041	694,879	1,060,687	8,128	9,650,000
Total Female	Cowpea	61	4,422	165,010	135,210	8,056	638,875
Total Male	Cowpea	408	27,315	262,239	954,817	3,056	10,700,000
Eastern							
Female	Mixed Beans	24	1,734	380,179	323,284	59,449	1,535,000
Male	Mixed Beans	153	10,109	529,328	774,270	8,128	5,000,000
Female	Cowpea	152	10,490	377,805	1,377,440	6,000	10,700,000
Male	Cowpea	27	1,888	182,262	136,986	39,413	638,875
Northern							
Female	Mixed Beans	41	3,803	788,538	1,279,234	18,000	6,000,000
Male	Mixed Beans	255	24,925	810,575	1,210,621	12,660	9,650,000
Female	Cowpea	9	668	113,638	108,006	21,620	369,973
Male	Cowpea	57	5,356	192,615	872,010	6,111	10,700,000
Southern							
Female	Mixed Beans	10	567	480,806	563,903	16,617	1,875,000
Male	Mixed Beans	87	5,007	453,167	576,748	16,617	3,901,324
Female	Cowpea	25	1,866	165,961	142,055	8,056	548,875
Male	Cowpea	199	11,469	189,059	271,487	3,056	2,614,376

Smallholder Producers' Perceptions About Relevant Policies

Producers' perceptions about five public policies were evaluated: seed and fertilizer subsidies, extension services, special training for producers, readily available markets, and producer price controls. Producers were asked to indicate the extent to which they believed government has used these policies to support or encourage bean and cowpea production. The bottom line was that producers did not see much public policy support for beans and cowpea production.

Enhancing Pulse Production in Zambia: Some Ideas

1. Provide education and training through the extension system and other programs to support the appreciation of potential food security value embedded in these crops, including the nonpecuniary value into their value estimates.

Seven Zambian citizens (six female, one male) completed bachelor's or master's degree programs in agricultural economics at the University of Zambia.

2. Identify opportunities within current institutions and infrastructure to aggressively enhance the management capacity along the whole supply chain.
3. Policies aimed at reducing the land and education resource gaps among females would be very helpful in facilitating the achievement of the nutritional objectives of Feed the Future. Changes in land transfer practices (often only to males) and educational incentives to keep women in long-term education will contribute to alleviating asset inequity over time.
4. Market expansion could contribute to production increases; however, it is imperative that production-increasing policies are developed in tandem with market expansion policies to prevent downward pressure on prices due to excess supply or poor market access to demand points.
5. Network the fragmented trader system into local associations so that individual transaction costs can be reduced.

INSTITUTIONAL CAPACITY BUILDING

Seven Zambian citizens (six female, one male) completed bachelor's or master's degree programs in agricultural economics at the University of Zambia. Seven Zambian citizens are expected to complete their bachelor's or master's degrees by spring 2013.

Short-term training in "Statistical and Econometric Analysis for Survey Data" was conducted for students and faculty to provide an overview of the tools for analyzing surveys at the University of Zambia in spring 2012. "Introduction to Governance Systems for Supply Chains" focused on training bean and cowpea traders in Lusaka in on October 2011.

A pilot governance mechanism was developed for a small group of traders between April and October 2012 to provide training on strategies to improve their procurement systems through collaboration and cost sharing.

Three students from Zambia completed the Kansas State University's Masters in Agribusiness (MAB) program with full scholarship

Three of the six participating undergraduate students who have completed their studies at the University of Zambia have received scholarships to pursue their master's degrees in the UK and South Africa.

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.

PIII-MSU-4

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ABSTRACT OF PRINCIPAL OBJECTIVES AND ACHIEVEMENTS

The project team completed the compilation of two databases: 1. Database of improved varieties of beans and cowpeas in countries where the Bean/Cowpea CRSP has been historically involved in crop improvement research, and 2. the database of socioeconomic studies and impact assessments conducted by the Dry Grain Pulses (and its predecessor) CRSP to date. The database on improved varieties and the impact studies was further scrutinized as part of the ongoing meta-analysis. The impact pathway analysis for each of the phase 2 and 3 projects was also completed and results presented to the management office.

The regional IRR was estimated at 32 percent, which suggests that investments in bean research in the four major bean producing countries of Central America (Honduras, Costa Rica, Nicaragua, and El Salvador) and Ecuador have provided returns well above the opportunity cost of capital.

Field research and analysis towards two ex post impact assessment studies was completed as planned, including the adoption and impact study on bean improvement research in Central America and Ecuador and the cowpea improvement research in Senegal. Results of the impact study in Central America indicate that in 2010, *Amadeus 77* (small red variety) was widely adopted in more than one country and accounted for approximately 50 percent of the area harvested with beans in Central America. The regional IRR was estimated at 32 percent, which suggests that investments in bean research in the four major bean producing countries of Central America (Honduras, Costa Rica, Nicaragua, and El Salvador) and Ecuador have provided returns well above the opportunity cost of capital.

The survey results for the Senegal study indicate that total adoption rate of improved varieties (IV) as reported by farmers in the three major cowpea growing regions was 44 percent. Adoption rate of the three Pulse CRSP varieties (*Melakh*, *Mouride,* and *Yacine*) was about 22 percent, with about 46 percent of the farmers growing at least one of the Pulse CRSP varieties. Results of the economic analysis indicate that past investments by the Bean/Cowpea CRSP and ISRA have produced an internal rate of return of 18 percent and a net present value of $78.6 million at a discount rate of 4.25 percent.

To implement an integrated impact evaluation strategy as part of the CRSP project design, the project team collaborated with several phase 1 and phase 3 project teams to conduct baseline assessment, design impact evaluations, and in-depth case studies. Studies initiated include:

1. Baseline assessment of the economic effects of pest problems on cowpea growing areas in Burkina Faso;
2. Impact evaluation to test the effectiveness and impacts of methods of extension to disseminate materials for IPM of cowpea pests; and
3. Case study of the bean seed multiplication and distribution system in Central America. As of the end of January 2013, two surveys in Burkina Faso, and three surveys in Nicaragua were completed. Data analysis and report writing will be completed as part of the extension phase.

PROBLEM STATEMENT AND RESEARCH APPROACH

Impact assessment is essential for evaluating publicly-funded research, capacity building, and outreach programs and for planning future research. Organizations that implement these programs should be accountable for showing results, demonstrating impacts, and assessing the cost-effectiveness of their implementation strategies. It is essential to document outputs, outcomes, and impacts of public investments in research for development activities.

Impact assessments are widely recognized to perform two functions—accountability (i.e., strategic validation) and learning—to justify continued support and to improve the effectiveness of development projects through review of both positive and negative experiences. Accountability and strategic validation have long been core concerns for ex-post impact assessments and learning has been primarily a concern of impact evaluation. The primary focus of this project was on ex post impact assessment, with impact evaluation of other Bean/Cowpea CRSP projects, as possible. In addition to measuring and evaluating impacts of past research investments, this project has also been concerned with increasing impacts from current investments by examining the impact pathways of research projects and inculcating an impact culture within the Pulse CRSP research community.

A simplified impact pathway model conceptualizes how investments affect developmental outcomes and impacts (Fig 1). The research inputs are conceptualized to generate outputs in the form of technologies and practices, goods and services, intellectual properties, and policies that are relevant to bringing about changes in the use of farm- and community-level resources and assets (land, labor, capital, entrepreneurship) to increase per unit production or marketing of outputs, products, and services or decreased risks and per unit costs at the farm household level (referred to as project outcomes in figure 1). The realization of projected outcomes requires adoption/uptake of research outputs at the end-user level (farmers, processors, consumers). Impacts on developmental goals (poverty reduction, environmental sustainability, food security, health) are realized when the outcomes are sufficiently scaled up and scaled out to a large number of beneficiaries.

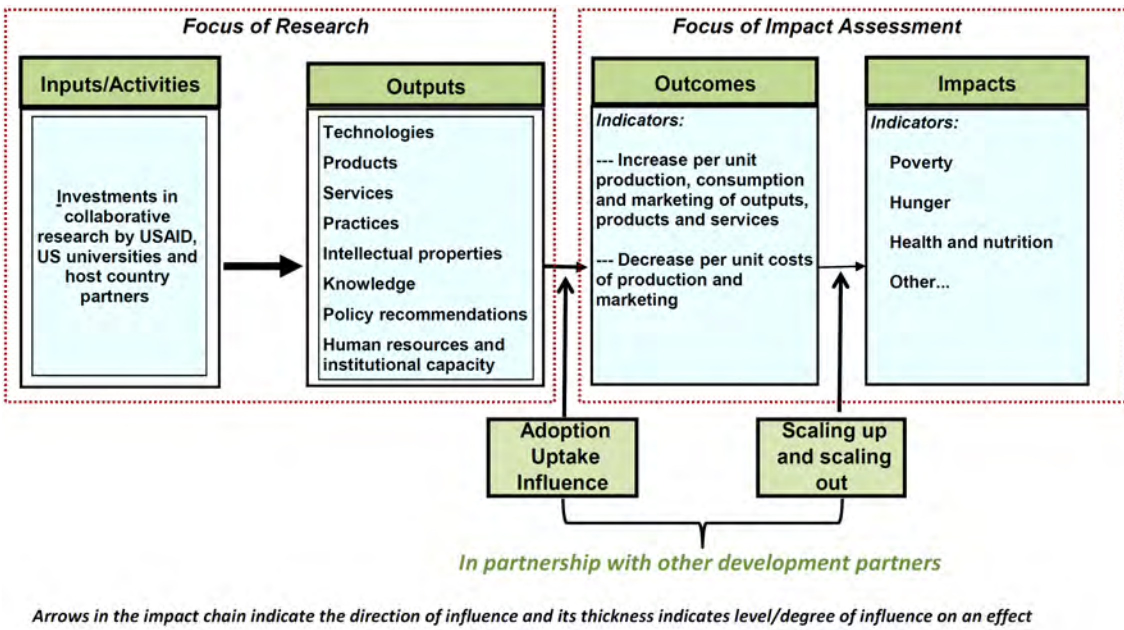

Figure 1. A generalized impact pathway of R&D activities funded by the Pulse CRSP

ACHIEVEMENTS AND OUTPUTS

Inventory of past outputs and documented impacts

Two databases were completed: a database of improved varieties in countries with Pulse and Bean/Cowpea CRSP crop improvement research and a database of socioeconomic studies and impact assessments conducted by these two CRSPs.

Figure 2 presents the number of bean and cowpea improved varieties released from 1980–2011 per five-year period by host country partners that received CRSP funding. Figure 3 shows the breakdown of the 145 bean varieties by country of release. Compared to beans, the number of cowpea improved varieties attributed to CRSP support has remained stable, at about five varieties per five-year period since the mid-1980s (fig 2). Figure 4 illustrates the release of cowpea varieties by country.

Past and current research conducted by the Bean/Cowpea and Pulse CRSP on value addition, food science, and human nutrition was reviewed with the aim of documenting all the outputs, outcomes, and impacts from such investments. This review indicated that the research in food science and human nutrition has generated many publications and scholarly outputs both in peer reviewed venues and in the form of theses and dissertations, which speaks of the high quality of scientific research underlying CRSP supported projects. However, this enquiry did not lead to any new or encouraging information on the commercial application of research outputs generated from CRSP research projects or evidence of their uptake/utilization by various actors in the value chain (i.e., processors, traders, consumers).

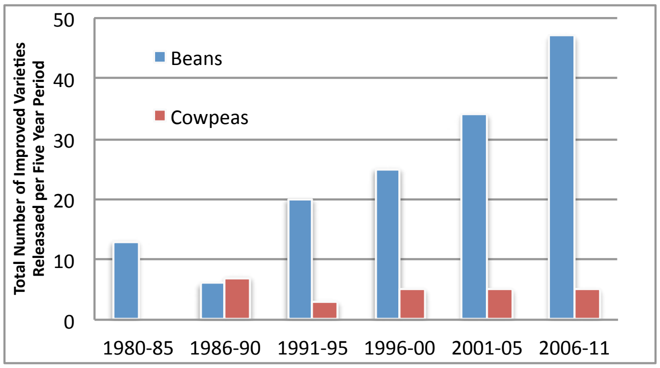

Figure 2. Trend in the number of improved bean and cowpea varieties released in CRSP partner countries (including USA) by breeding programs that received CRSP funding, 1980–2011.
Source: Variety database compiled by CRSP IA team, 2011

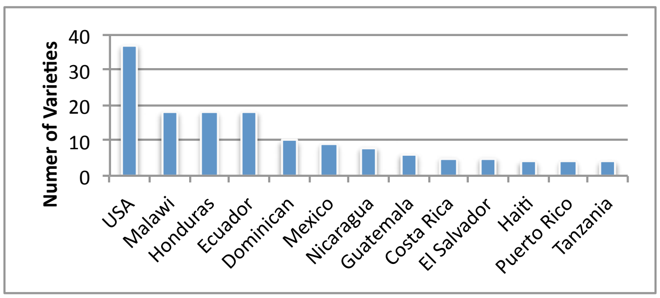

Figure 3. Number of CRSP-supported, improved bean varieties released in different countries, 1980–2011
Source: Variety database compiled by CRSP IA team, 2011

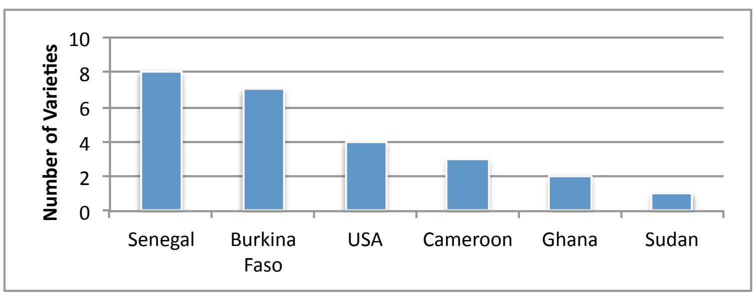

Figure 4. Number of CRSP-supported, improved cowpea varieties released in different countries, 1986–2010
Source: Variety database compiled by CRSP IA team, 2011

The impact database contains a list of 40+ studies of varying focus and rigor on quantitative assessment of impacts. Not surprisingly, a majority of studies assess the ex post adoption or farm-level benefits of varietal outputs of CRSP research. However, there are also a few studies that examine the impact of cowpea storage technology in Africa and IPM research.

Trajectory of outputs and potential outcomes/impacts of ongoing Pulse CRSP investments

Focused on ongoing phase 2 and 3 projects, this analysis captures the projects' outputs, outcomes, and impacts presented in a spreadsheet for the end of FY 2012 and the next five years. Based on this analysis, the ten phase 2 and 3 projects were grouped into three areas: 1) projects for which the potential of achieving development impacts is high; 2) projects for which the potential for long-term impacts is low; and 3) projects for which the potential for long-term impacts is uncertain due to factors outside researchers' control.

Synthesis study on the adoption and impact of CRSP's bean improvement efforts in the LAC region

The adoption of improved bean varieties in 2010 across the five focused countries (Honduras, El Salvador, Nicaragua, Costa Rica, and Ecuador) was estimated at 67 percent of the area harvested to small red beans in Central America and 50 percent of the area harvested to red mottled beans in northern Ecuador. For most countries, total adoption of red/red mottled IVs has increased since 1996.

The economic analysis of improved small red and red mottled bean varieties for the period 1991–2015 indicates that returns to investments by national and international partners in bean research have been positive in all focused countries, except Costa Rica. The NPV of benefits from these research investments across all five countries was estimated at $359 million (for details, see Table 1).

In Costa Rica, negative net gains were observed because both the total bean area and the area planted to IVs have decreased over time. Further, small red beans represent a much smaller proportion of the total bean area planted compared to black beans. In Costa Rica, future research on small red varieties should give priority to developing varieties that are more acceptable to farmers (i.e., light reds) to increase adoption rates. Furthermore, since black beans are the most widely produced market class, increased efforts should be devoted to developing new black IVs. The results of this study support the continuation of current research since investments have paid off.

Table 1. Summary of NPV and IRR (%) estimations for Central America and northern Ecuador, 1991–2005.

	Scenario (in constant 2009 US$)						For 1997–2015
	Base		Scenario A		Scenario B		Producer surplus per ha per year ($)
Country	NPV($)	IRR	NPV($)	IRR	NPV($)	IRR	
Costa Rica	-2,016,054	-5%	-1,610,978	-3%	Not estimated		26
El Salvador	77,510,816	40%	93,170,299	43%	62,688,130	37%	84
Honduras	58,250,437	34%	73,724,174	37%	43,698,030	31%	63
Nicaragua	214,002,964	42%	254,621,317	45%	175,583,202	39%	73
Ecuador	10,920,047	37%	13,216,135	39%	8,832,204	35%	196
Central American countries	347,748,163	32%	419,904,813	35%	281,969,362	32%	72
All countries	358,668,210	32%	433,120,948	35%	290,801,566	32%	74

Economic Assessment of the benefits of genetic improvement of cowpea in Senegal and West Africa

CRSP's investment in Senegal led to the development and dissemination of three determinant, short-cycle cowpea improved varieties: Melakh, Mouride, and Yacine. The adoption rate for these varieties in the study regions is 40 percent and for all improved varieties 48 percent. Adoption rates within the regions differ significantly, as detailed in figure 5.

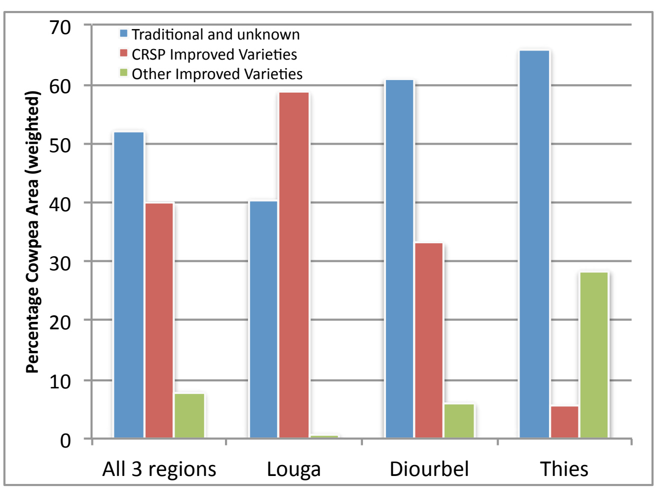

Figure 5. Adoption of improved varieties in study regions in Senegal
Source: Cowpea survey 2011

The yields of cowpea grain for the three Pulse CRSP varieties and traditional varieties (TVs) based on the survey results are presented in table 2.

Table 2. Median grain yields by variety (kg/ha), 2010 season
Source: Cowpea survey, 2011

	Cowpea Varieties			
Region	**Melakh**	**Mouride**	**Yacine**	**Traditional**
Diourbel	218.0	No obs.	206.2	146.6
Thiès	460.7	No obs.	144.0	123.1
Louga	393.9	687.8	400.3	267.8

Researchers in Senegal developed early-maturing cowpea varieties to help farmers improve household food security when food from the previous harvest is often depleted. Melakh, Mouride, and Yacine are all dual-purpose dry grain/fresh cowpea varieties that mature in fewer than 65 days. As such, they are available for consumption as green pods two weeks before traditional varieties. Households can either consume the green pods or sell them to increase household income.

Survey results confirm that 87 percent of farmers consider green pods a significant contributor to their family's food sources and 21 use them as a revenue source. Less than one percent do not harvest green pods.

Given the importance of harvesting improved varieties as green pods, the grain yields reported in table 2 underestimate the true value of production per hectare of these varieties compared to traditional varieties. For example, annual green pod to dry grain production in Diourbel was 0.41 kg green pods per kg of dry grain. Based on the price data reported in the survey for green pods and dry grain, the total production of cowpea was converted into value of production and outlined in table 3. There is a clear gain in dollars per hectare from planting improved varieties.

	Total Value of Production (US$/ha)
Melakh	300
Mouride	498
Yacine	186
Traditional	171

Table 3. Total value of cowpea production by variety
Source: Cowpea Survey 2011

Adoption rates from the 2011 survey and the 2004 study were used to project adoption curves for each variety within each region. The results indicate that the IRR for the project is 17.9 percent when projecting benefits through 2020 and 12.9 percent projecting benefits through 2010. The Net Present Value (NPV) using benefits through 2020 is $78.6 million, at a discount rate of 4.25 percent.

The economic impact analysis found that Pulse CRSP and ISRA investments in cowpea varietal improvement have been profitable in Senegal, significantly exceeding research, development, and extension costs.

While the adoption improvements in Louga have led to profitable gains, the lack of significant yield gains in Diourbel and questions about adoption in Thiès suggest a need for further research into farmer adoption patterns, potentially increasing the adoption and impact of cowpea research efforts in Senegal

Baseline assessment of the economic effects of pest problems on cowpea growing areas in Burkina Faso

This was a joint activity with the PII-UIUC-1 project team. To address such field insect pest problems as legume pod borer, bruchids, and pod sucking bugs for which conventional breeding has not been effective, the UIUC-1 project has developed alternative strategies for controlling these insect pests to reduce pesticide levels on cowpea crops, including a comprehensive biocontrol program, which should generate health and environmental benefits from reduced pesticide use and economic benefits from increased productivity. These impacts depend on the movement and spread of biocontrol agents in relation to the pest population's location and the pest control strategies farmers use in the absence of biocontrol agents.

Estimating the long-term benefits of this research requires a better understanding of the pest population's spatial distribution, tracking the movement and spread of biocontrol agents over time, and a change in farmers' pest control practices due to biocontrol agents in the environment. The UIUC project is collecting data towards the first two types of information for future impact assessment; in FY12, baseline household-level data were collected to assess the impact of biocontrol research after several years of cumulative efforts in Burkina Faso.

A total of 560 households were interviewed across 56 villages in early 2012. Although the analysis is in progress, selected statistics are available.

On average, 95 percent of households planted between one and two cowpea fields. While 54 percent of households applied chemical fertilizer to at least one cowpea field, only 40 percent applied organic fertilizer (i.e., manure). In contrast, 78 percent of households applied chemical or organic insecticides and 65 percent of households applied fungicides to their cowpea fields. Only 7.3 percent of farmers knew about beneficial insects and 2.6 percent about beneficial viruses, indicating that education is needed; only 14.6 percent of farmers' households had received previous IPM training.

Impact evaluation to test the effectiveness of methods of extension to disseminate materials for IPM of cowpea pests

As part of the collaborative Pulse CRSP research project, UIUC and INERA plan to pilot test the deployment of these two animated videos in selected villages in Burkina Faso using the government extension system.

Case study of the bean seed multiplication and distribution system in Central America

Several seed multiplication and distribution system models are also being used by the Pulse CRSP in its Bean Technology Dissemination (BTD) project in Honduras, Haiti, Guatemala, and Nicaragua. The model in Nicaragua is based on community-managed and operated seed banks in which community members together produce seeds to meet their own current needs, save seeds for future seed security, and sell excess seeds to generate revenues to cover production costs. In Honduras, the model is based on farmer associations managing seed multiplication and distribution. In Guatemala, the public sector plays a major role throughout the seed value chain. In Haiti, the project is trying a dual approach in which the private sector sells seeds through retail outlets and the public sector distributes seeds to resource-poor farmers.

This seed dissemination project offers a good opportunity to analyze the different models for seed multiplication and distribution, potentially deriving implications for broader applicability. To this end, the project has a research study focused on identifying "elements of sustainability of the bean seed system." As part of this study, the project team has completed three surveys:

In August 2012, 480 Nicaraguan farmers who were the beneficiaries of the BTD's seed distribution efforts in 2011 were surveyed on their perceptions of CSB operations.

1. a survey of 153 Community Seed Banks (CSB) in Nicaragua 2. a survey of 480 Nicaraguan farmers who received bean seed in 2011 and 3. the cost of production record keeping by the Nicaraguan CSBs during the Primera planting season 2012.

The preliminary analysis of the survey of Community Seed Banks (CSB) in Nicaragua indicates that the average CSB was formed by seven members and had 21 percent female participation. In 29 communities, a single farmer acted as the CSB by multiplying and disseminating seed to his or her community. In another region, a group of seven experienced seed producers formed a centralized seed multiplication and dissemination effort for six neighboring communities.

In August 2012, 480 Nicaraguan farmers who were the beneficiaries of the BTD's seed distribution efforts in 2011 were surveyed on their perceptions of CSB operations as a seed multiplication and dissemination source in their community. The survey also asked about the quality of seed produced by the CSBs. Data is still being analyzed.

During the *primera* planting season 2012, seed production costs were recorded for each Nicaraguan CSB to estimate the cost of operation and conduct a cost–benefit analysis of the CSB model. The data from this record-keeping exercise is still being compiled.

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

Although this project does not include a host-country partner as in other Pulse CRSP projects, it does address the objective of institutional capacity building and human resource development through the following methods:

1. Field activities were conducted in collaboration with HC PIs and partners.
2. Assessment of projects and subsequent recommendations are conducted in collaboration with U.S. and HC PIs.
3. The activities planned under this project involved four graduate students in the planning and conduct of field research.

KEY PUBLICATIONS

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 p.

Impact Briefs

Based on research conducted and previous ex post impact studies, the project team developed and published four *Impact Briefs*, which are now a permanent feature of the Pulse CRSP website, to disseminate the impact stories of USAID's investments in the Pulse CRSP (and its predecessor, the Bean/Cowpea CRSP):

1. *Improved bean varieties in Central America and Ecuador generate economic benefits to farmers*
2. *Sustaining a steady flow of high yielding, improved bean varieties through the bean research network in Central America*
3. *Farmers in West and Central Africa obtain economic benefits from enhanced cowpea storage technologies*
4. *Economic impact of CRSP's investment in the development and dissemination of improved cowpea varietal technology: New evidence from Senegal*

Capacity Building Under the Dry Grain Pulses CRSP

The Dry Grain Pulses Collaborative Research Support Program was established with a mandate to conduct high quality science research and to build up the long-term scientific capacity in our host countries and regions through collaborations between U.S. and host country scientists. Three mechanisms were established to ensure continued research and extension investments on pulses in developing countries. First, and most recognized, was the incorporation of funding for formal degree studies within each of the Pulse CRSP projects. Second, each project developed short-term training modules to reach even greater numbers of scientists and collaborators within the many host countries. (For each project under the Pulse CRSP, a minimum of 30 percent of direct costs were to be invested in these first two capacity-building mechanisms.) Finally, a special fund was established for competitively allocated capacity-building projects, primarily with host country institutions.

Formal Degree Training

During the 2007–2013 period, 63 participants obtained degrees under Pulse CRSP funding (Table 1). Another 17 students are continuing with leveraged funding or funding from the Legume Innovation Lab to complete their degrees in the next few months or years. As table 1 indicates, 49 percent of the training participants are women and 85 percent are from West, East, and Southern Africa. Taking advantage of national and regional programs of study, 73 percent obtained (or will obtain) their degrees from their own or third countries. For example, an Angolan received his M.S. degree from the University of Vicosa in Brazil, a Rwandan candidate obtained a degree from the University of Pretoria in South Africa, and several Zambian students obtained M.S. degrees in either agricultural economics or nutrition from the University of Zambia. As indicated in table 1, many of the students still pursuing their degrees are undertaking Ph.D.s. Because host country

Table 1.

Trainees FY 2008–FY2012	Active		Completed		Total	
	Number	% of total active trainees	Number	% of completed trainees	Number	% of all trainees
Gender						
Male	7	41%	34	54%	41	51%
Female	10	59%	29	46%	39	49%
Region of Origin						
East Africa	4	24%	19	30%	23	29%
Southern Africa	6	35%	23	37%	29	36%
West Africa	5	29%	11	17%	16	20%
Latin America/Caribbean	1	6%	5	8%	6	8%
United States	1	6%	2	3%	3	4%
Other	0	0%	3	5%	3	4%
Degree program						
Ph.D.	8	47%	10	16%	18	23%
M.S./MAB	6	35%	41	65%	47	59%
B.S.	3	18%	12	19%	15	19%
Training Location						
U.S.	4	23%	18	28%	22	27%
Host countries	10	59%	37	59%	47	59%
Third countries	3	18%	8	13%	11	14%
Total	17		63		80	

Notes: Status is based on information as of March 2013.

Active indicates that they are continuing their studies and are on track to obtain degrees with Legume Innovation Lab funding or with leveraged funding from other sources.

institutions often prioritize Ph.D.s as critical investments for their long-term capacity, Pulse CRSP researchers obtain leveraged funding for these candidates to ensure that they have adequate resources and time to complete their education programs.

A key element of the Pulse CRSP formal degree training model linked students to ongoing research and researchers in their home countries as well as to leaders in their field from U.S. universities, the U.S. Agricultural Research Service (ARS), and other international institutions, including the Consultative Group on International Agricultural Research (CGIAR). Additionally, a Pulse CRSP scientist, usually the local principal investigator or an international scientist, sits on the research or guidance committee of nearly all students. This arrangement not only ensured that the research would be valuable locally, but more importantly, that the returning students would have a continued role in national research, and educational and development institutions as degreed scientists. Finally, their degree programs help them to establish professional linkages to guide their careers forward and motivate continued work in pulses.

This formal training investment can be costly, but leaders in the national agricultural research systems agree that such exposure to high quality, cutting-edge research, in addition to the key science concepts, helps motivate local researchers and enables retention of these degreed scientists upon their return from training.

Nondegree and Short-term Training

Nondegree and short-term training activities were designed within Pulse CRSP projects to build the capacity of local institutions and to reach a broader local audience with specific areas of expertise. This training included organized workshops, group training, short-term individualized training at CRSP participating institutions, and participation in networking activities with peers working on pulses—locally and/or internationally. Training activities typically lasted only a few days, usually in the form of workshops; some, however, involved highly structured learning experiences extending from a few weeks to several months or a year with individualized instruction in a lab or field setting. As with degree training, all nondegree training was integrated with research activities and incorporated into the annual research workplans of each project. A total of 15,000 people attended training in Pulse CRSP project countries. These events also brought together scientists across a region to examine methods and alternative approaches to various challenges, allowing the knowledge from several projects to be shared and utilized, when appropriate, most expediently.

These training sessions ranged across the disciplines, as per the examples below:

- Analysis of market prices for pulses in Angola and Mozambique (12 Ministry of Agriculture analysts in Mozambique and 21 students and NGO staff members in Angola)
- Identification of bean diseases and pests (eight analysts from IIA, Angola)
- Use of improved methods of crop management and postharvest handling for common beans to reduce losses due to pests (67 Ugandan farmers under NGO VEDCO)
- Recent advances in techniques to screen for biotic and abiotic stress resistance in beans and cowpeas (20 trainees in Honduras)
- Molecular biology tools for integrated pest management strategies and computational modeling for Burkina Faso (training for a Malian scientist at UIUC)
- Food safety training on Hazard Analysis Critical Control Points (two participants from Sokoine University, Tanzania, at MSU)

These short-term training opportunities are valuable for staff who do not need advanced degrees for their work, who cannot take time away from their base for formal training, or when a highly specific method can be communicated in a brief training session. Farmers also appreciate brief trainings that allow them to avoid being absent from their fields for long periods. The training materials developed were often used repeatedly in training new groups of people, a feature appreciated by the host country institutions.

Equipment and Other Investments for Host Country Capacity Building

Competitive funds were allocated to special capacity building investments throughout the Pulse CRSP project period. Each year, host country institutions, in collaboration with U.S. PIs, developed proposals to request funding for specific investments that they considered priority to sustain and improve their work. The Technical Management Advisory Committee, with input from the Management Office, selected proposals for funding from the pool of proposals submitted. Host country PIs were especially appreciative of these investments, which stemmed directly from collaboration with the Pulse CRSP and were often able to leverage them for a larger overall gain.

Each fiscal year, a selection of projects was made and disbursement authorized:

- FY2012: $107,371.00
- FY2011: $252,097.00
- FY2010: $72,500.00
- FY2009: $176,465.50

These funds were mainly used for equipment or special training to enhance the overall effectiveness of the host country institution's research program. In addition to special training sessions, investments included irrigation equipment for seed production, vehicles to reach distant research sites, laboratory equipment, and video equipment for developing training materials. The Pulse CRSP funded the implementation of an international research conference on "Enhancing Pulse Productivity on Problem Soils by Smallholder Farmers: Challenges and Opportunities" at Pennsylvania State University and the participation of scientists in the World Cowpea Conference in Senegal.

Annex Table 1. Capacity building projects funded by the Pulse CRSP for FY 2008–2012

Project	Benefitting Institution	Year awarded	Topic	Budget
PI-CU-1	Kenya Agricultural Research Institute (KARI)	2009	Build capacity building of KARI through the training of two M.Sc. students in Kenya	$12,678.00
PI-ISU-1	Kigali Institute of Science and Technology (KIST), Rwanda	2009	Purchase of a single bore extruder to strengthen the research capacity of KIST in food science and to create opportunities to develop value-added, bean-based processed foods	$6,050.00
PI-ISU-1	Makerere University, Uganda	2009	Short-term training of M.Sc. graduate student (Catherine Ndagire) from Makerere University at Iowa State University	$7,320.50
PI-MSU-1	Institut des Sciences Agronomiques du Rwanda (ISAR)	2009	Purchase of equipment and supplies to establish a molecular genetics lab to conduct marker assisted breeding	$20,000.00
PI-PSU-1	Agricultural Research Institute of Mozambique–IIAM	2009	Purchase of several pieces of equipment in support of root biology research at Sussundenga and bean breeding research at Chokwe	$21,100.00
PI-UCR-1	Institut de l'Environnement et de Recherches Agricoles (INERA), Burkina Faso	2009	Purchase of a new vehicle for the cowpea breeding program of INERA in Burkina Faso	$39,000.00
PI-UCR-1	Instituto de Investigacão Agronómica (IIA), Angola	2009	To purchase equipment to establish a functional pathology laboratory at IIA–Angola (environment controlled incubator shaker cabinet, a dissecting microscope, and supplies)	$10,000.00
PI-UCR-1	ISRA-Senegal	2009	Short-term training of technical staff in identification, isolation, culture, and conservation of bean pathogens	$3,500.00
PI-UIUC-1	INRA/Niger; INERA/Burkina Faso; IER/Mali; ISRA/Senegal; IITA (West Africa); other NARS in West Africa	2009	To host a workshop on the biocontrol of cowpea pests in conjunction with the Fourth World Cowpea Conference in Dakar, Senegal	$11,197.00

Annex Table 1. Capacity building projects funded by the Pulse CRSP for FY 2008–2012 (cont.)

Project	Benefitting Institution	Year awarded	Topic	Budget
PI-UPR-1	Escuela Agrícola Panamericana (Zamorano), Honduras	2009	Improvement of basic seed production and storage facilities in Central America, Haiti, and Angola	$11,000.00
PI-UPR-1	Escuela Agrícola Panamericana (Zamorano), Honduras	2009	Organize workshop at the upcoming PCCMCA Meetings to review the current situation of bean production, consumption, and commercialization in CAC; to identify opportunities to adopt new technologies and to determine if new traits need to be evaluated; to identify how NBR programs can have a greater level of participation in the generation, development, and testing of bean breeding lines	$10,000.00
PI-UPR-1	Instituto de Investigacão Agronómica (IIA), Angola	2009	Improvement of basic seed production and storage facilities in Angola	$12,820.00
PI-UPR-1	Ministry of Agriculture, Haiti	2009	Improvement of basic seed production and storage facilities in Haiti	$11,800.00
PIII-MSU-4	INERA, Burkina Faso	2010	Collection and assessment of appropriate farm-level data to capture the effects of IPM extension messages and methods on changes in farmer knowledge, perceptions, and behavior in Burkina Faso.	$10,000.00
PIII-UIUC-1	IITA–Benin	2010	Development of a delivery system for ednophytic strains of *Beauveria bassiana* and *Metarhizium anisopliae* against cowpea pod borer and development of sustainable virus production at the farmer level in West Africa	$20,000.00
PII-UCR-1	ISRA–Senegal	2010	Training of CRSP cowpea breeders in the development and application of DNA-based markers for MAS in West African cowpea breeding programs.	$10,000.00
PII-UPR-1	NSS–Haiti	2010	Acquisition of a 4WD vehicle for the NSS, Ministry of Agriculture, for field evaluation of bean breeding line performance and the production of seed for dissemination to farmers in Haiti.	$32,500.00
MO	Various	2011	Sponsoring of 23 lead PIs (U.S. and host country) to attend 5th Annual World Cowpea Conference in Saly, Senegal	$77,097.00
PII-MSU-2	IIAM, Mozambique; UJES, Angola	2011	Simple, low cost video equipment and software. Training for agricultural research in Mozambique and university training in agriculture in Angola	$25,300.00
PII-PSU-1	Various	2011	Workshop on “Enhancing Pulse Productivity on Problem Soils by Smallholder Farmers: Challenges and Opportunities,” at Pennsylvania State University	$100,000.00

Annex Table 1. Capacity building projects funded by the Pulse CRSP for FY 2008–2012 (cont.)

Project	Benefitting Institution	Year awarded	Topic	Budget
PII-UIUC-1	INERA, Burkina Faso, and NGOs, Niger	2011	An assessment of the availability of cell phones among extension agents, NGO staff, and farmers and of their skill sets and abilities to use the video and Bluetooth capacities of their phones in Burkina Faso and Niger to receive and to deploy IPM messages for the management of insect pests in cowpea	$22,000.00
PII-UPR-1	Various: Zamorano Honduras; IIAM, Mozambique; IIA, Angola	2011	Workshops held to train participants on Rhyzobium inoculant production and inoculation for NARS in Central America and for NARS in Mozambique and Angola	$27,700.00
PII-ISU-1	VEDCO, Uganda	2012	Development of training materials on improved bean management practices, evaluation of training methods, and capacity building of VEDCO staff in Uganda	$20,000.00
PII-PSU-1	IIAM–Mozambique	2012	Acquisition of refrigerator for seed storage and irrigation pump for Chokwe Research Center, IIAM, Mozambique	$12,071.00
PII-UCR-1	Various	2012	Training program in the development and application of DNA-based markers for Marker Assisted Selection (MAS) for use in cowpea breeding programs at Kigali meetings, and in Addis Ababa, Ethiopia	$10,000.00
PII-UPR-1	IIA, Angola	2012	Equipment and supplies for plant pathology laboratory and repair of greenhouses at IIA Research Station at Huambo	$25,300.00
PII-UIUC-1	INERA, Burkina Faso, and NGOs, Niger	2012	Development and deployment of practical technologies: four videos	$40,000.00
			Total Investments	**$608,433.50**

Management Office Report Dry Grain Pulses CRSP (2007–2012)

Introduction

The objective of the *Five-Year Technical Report of the Dry Grain Pulses CRSP* is to highlight the significant and substantive achievements, outputs, and developmental outcomes of the collaborative research, education, and training activities supported by this Collaborative Research Support Program in Africa and Latin America in 17 countries (Benin, Burkina Faso, Mali, Niger, Nigeria, Senegal, Kenya, Rwanda, Uganda, Tanzania, Mozambique, South Africa, Zambia, and Angola, and Haiti, Honduras, and Ecuador) over the five-year course of this project.

Because the Management Office provided technical leadership to program planning, implementation, and performance monitoring, and administered the contractual and financial aspects of the program, it is important to recognize the MO's contribution to the quality, productivity, and impact. For this reason, this five-year report will focus on the goals, challenges, and accomplishments of the administration of Pulse CRSP during this five-year award period. The purpose of the MO report is not to summarize the technical achievements of the program but to present information and perspectives useful to USAID, Washington, D.C., the sponsoring agency for this program, as well as other U.S. universities that might manage a USAID project in the future.

Recompetition of the Management Entity for the Dry Grain Pulses CRSP

In response to a Request for Assistance issued by the Office of Economic Growth, Agriculture and Trade, USAID, Washington, Michigan State University submitted a *Technical and Cost Application* to USAID in 2006, proposing a two-phase research and capacity building program addressing four themes for dry grain pulses:

1. **To reduce bean and cowpea production costs and risks for enhanced profitability and competiveness.** This theme focused predominantly on genetic improvement of pulses for increased resistances to biotic and abiotic stresses and to enhance the genetic yield potential of pulse varieties by smallholder farmers in Latin America and Africa.
2. **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.** This theme addressed postharvest handling and nutrition research to better understand the role of the nutritional and health value of pulses in diets.
3. **To improve the performance and sustainability of bean and cowpea value chains, especially for the benefit of women.** This theme focused particularly on understanding pulse market structure and function and on strengthening governance of pulse value chains.
4. **To increase the capacity, effectiveness, and sustainability of agriculture research institutions that serve the bean and cowpea sectors and developing countries.**

The global vision behind these four themes was to contribute to:

- Economic growth and food and nutritional security through knowledge and technology generation
- Sustainable growth and competitiveness of pulse value chains utilizing socially and environmentally compatible approaches
- Empowerment and strengthened capacity of agriculture research institutions in USAID priority countries

- Achievement of USAID's developmental objectives as defined in the *Policy Framework for Bilateral Foreign Aid* and the *Presidential Initiative to End Hunger in Africa (IEHA)*
- Achievement of Title XII legislation objectives including the provision for dual benefits to developing country and U.S. agriculture.

In response to this application, in 2007 USAID awarded a five-year, $9 million dollar Leader with Associate Cooperative Agreement award to Michigan State University to serve as the Management Entity for the Dry Grain Pulses CRSP.

Program Implementation

Having received the CRSP award from USAID, the Management Office issued RFPs addressing the four themes, for which 27 proposals were received. The MO convened a five-person External Evaluation Panel of university and government experts on pulses and nutrition to evaluate these proposals and to advise the MO on which projects to fund. Eight proposals were selected and cost-reimbursable contracts for 2.5 years were awarded to Lead U.S. universities, which established fixed price contracts with collaborating host country and other U.S. institutions collaborating on the project. The projects were chosen and awarded within six months of the program's beginning; called the Phase I projects, they were as follows:

1. Using Improved Pulse Crop Productivity to Reinvigorate Smallholder Mixed Farming Systems in Western Kenya (PI-CU-)
2. Enhancing Nutritional Value and Marketability of Beans through Research and Strengthening Key Value Chain Stakeholders in Uganda and Rwanda (PI-ISU-1)
3. Combining Conventional, Molecular and Farmer Participatory Breeding Approaches to Improve Andean Beans for Resistance to Biotic and Abiotic Stresses (PI-MSU-1)
4. Expanding Pulse Supply and Demand in Africa and Latin America: Identifying Constraints and New Strategies (PI-MSU-2)
5. Improving Bean Production in Drought-Prone, Low Fertility Soils of Africa and Latin America—An Integrated Approach (PI-PSU-1)
6. Modern Cowpea Breeding to Overcome Critical Production Constraints in Africa and the U.S. (PI-UCR-1)
7. Biological Foundations for Management of Field Insect Pests of Cowpea in Africa (PI-UIUC-1)
8. Development, Testing and Dissemination of Genetically Improved Bean Cultivars for Central America, the Caribbean and Angola (PI-UPR-1)

These eight projects involved collaborative research, long- and short-term training, and technology dissemination activities in eight African countries (Burkina Faso, Benin, Niger, Kenya, Rwanda, Uganda, Mozambique, and Angola) and three Latin American countries (Haiti, Honduras, and Ecuador). Within this group, several were designated as USAID priority countries under the "Presidential Initiative to End Hunger in Africa."

Administrative Oversight

To ensure MO oversight, a Technical Management Advisory Committee (TMAC) was formed to review project annual workplans, technical progress reports, and performance indicators. TMAC monitored the scientific quality and productivity of projects, recommended adjustments when necessary, and identified and advised the MO on strategic topical areas for future RFPs.

The TMAC is composed of eight members, who have varied over the five years of the award (which explains why the number of representatives and the actual person count do not match): one external legume scientist with international stature (Douglas Maxwell), one industry representative (Bob Green and Greg Varner), two representatives from CGIAR (Steve Beebe, Ousmane Coulibaly, Ousmane Boukar), three Legume Innovation Lab PIs (Jim Beaver, Jill Findies, Ndiaga Cisse, Amanda Minnaar, Barry Pittendrigh, Cynthia Donovan, Mywish Maredia), and the AOR (Bahiru Daguma, Larry Beach, and Jennifer "Vern" Long). The TMAC met one to three times a year, sometimes via conference call, to review annual workplans and budgets, review institutional capacity building proposals, and evaluate annual technical progress reports for each project. Through site visits and consultants, the TMAC monitored the quality and performance of research activities within the subcontracted projects.

- Doug Maxwell and Amanda Minnaar visited the PI-ISU-1 and the PIII-ISU-2 projects in Kampala, Uganda, and Morogoro, Tanzania.
- Ndiaga Cisse conducted a site visit of the PI-CU-1 project in Western Kenya.
- Donna Winham, Arizona State University, was contracted to conduct a site visit of the PIII-MSU-3 project in Tanzania.
- Cynthia Donovan and Barry Pittendrigh visited the PIII-KSU site in Zambia.

The Pulse CRSP director and/or deputy director also conducted project site visits over the five-year grant period: PII-UCR-1 (Riverside, CA), PII-MSU-1 (Rwanda), PII-UPR-1 (Puerto Rico and Zamorano, Honduras), PII-ISU-1 (Rwanda), PII-CU-1 (Kenya), PII-PSU-1 (Mozambique and State College, PA), PIII-ISU-2 (Uganda and Kenya), PIII-TAMU-1 (Zambia and Kenya), PIII-MSU-3 (Tanzania). These visits provided valuable insights into the technical progress being made, the commitment and engagement of the scientists and participating institutions, and the needs for institutional capacity building in the projects.

After the initial 2.5-year grant period, the TMAC evaluated each of the Phase I projects for possible extension as Phase II projects. With the exception of the Cornell-led project, *Using Improved Pulse Crop Productivity to Reinvigorate Smallholder Mixed Farming Systems in Western Kenya* (PI-CU-1), the TMAC recommended that all the Phase I projects be extended through September 30, 2012, but with some refocusing.

Through the remainder of the award period, the TMAC continued to monitor projects, including the four Phase III projects added in 2009 (see next section), and to advise the Management Office (MO) on strategic planning for the five-year extension (2012–2017). The MO regularly consulted with the TMAC on emerging issues and technologies, strategies for building sustainable institutional capacity and achieving development impacts, and program management issues.

Increase in Program Authorization and New Awards

In 2010, half way into the program, USAID increased the authorization and obligation of the Pulse CRSP from $9 million to $14.014 million through September 29, 2013. This increase required the MO to prepare a revised technical application and budget to justify the increased authorization. The revised technical application proposed that the $5 million in new funds be allocated to three new three-year research projects (designated Phase III projects), to technology dissemination, and to a project on impact assessment. The following four projects were competitively awarded through the RFP and external peer review process, while the impact assessment project was awarded to Dr. Mywish Maredia, impact specialist in the Dry Grain Pulses CRSP MO.

- Enhancing Biological Nitrogen Fixation of Leguminous Crops Grown on Degraded Soils in Uganda, Rwanda and Tanzania. ISU, Mark Westgate, lead PI. (PIII-ISU-2)
- Pulse Value-Chain Initiative— Zambia. KSU, Vincent Amanor-Buadu, lead PI. (PIII-KSU-1)

- Improving Nutritional Status and CD4 Counts in HIV-Infected Children through Nutritional Support. MSU, Maurice Bennink, lead PI. (PIII-MSU-3)
- Increasing Utilization of Cowpeas to Promote Health and Food Security in Africa. TAMU, Joseph Awika, lead PI. (PIII-TAMU-1)
- 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. MSU, Mywish Maredia, lead PI (PIII-MSU-4)

Technology dissemination funding was provided to three projects: PII-UPR-1 and PII-UCR-1 to multiply and increase availability of foundation seed of CRSP common bean and cowpea varieties to seed producers and smallholder farmer groups and to PII-UIUC-1 for enhancing dissemination of IPM-omics solutions utilizing animation videos targeting low-literacy farmers. Increased funding to PII-UPR-1 and PII-UCR-1 resulted in significant increases in the development and release of disease resistant bean and cowpea cultivars in Central America and Haiti, and in Senegal and Burkina, respectively. Quality seed of the improved varieties has been widely disseminated to more than 100,000 farmers in these countries.

Global Meetings

During the 2007–2012 award period, the Pulse CRSP convened three global meetings: 2008 in Barcelona, Spain; 2010 in Quito, Ecuador; and 2012 in Kigali, Rwanda.

The first meeting allowed U.S. and HC PIs to become acquainted with and learn about the new portfolio of projects in the Pulse CRSP and to take initial steps in coordinating research and capacity building activities both within and among projects working in similar regions or on similar pulse commodity value chains. In addition, operational guidelines and policies of the Dry Grain Pulses CRSP were explained and technical and financial reporting requirements and processes outlined to PIs.

The second meeting, cohosted by INIAP–Ecuador, was convened after the awarding of the PIII projects. As in the first meeting, this global meeting provided an opportunity for Phase III U.S. and HC PIs to get to know one another, plan their projects in greater detail, and coordinate research and capacity building activities, as appropriate. Project teams extended from the first phase (Phase I) met to plan Phase II activities and to explore linkages and to coordinate their research with the crosscutting value chain and nutrition projects. In response to a TMAC recommendation, significant time was allocated for projects to discuss and plan “Impact Pathways” for projected outputs from the respective project research activities. With the assistance of Mywish Maredia, each project team was required to prepare an Impact Pathway Plan.

The final global meeting, held in Kigali, Rwanda, and cohosted by the Rural Agriculture Board–Rwanda, brought together the entire international community of Pulse CRSP PIs, collaborators, and partners—more than 120 persons. Attendees included delegations from CIAT, IITA, and Dave Hoisington, Deputy DG for Research at ICRISAT and interim director of the new CGIAR CRP 3.5 on Grain Legumes. In addition, numerous USAID Missions in the Central and Eastern Africa Region attended along with representatives of other international pulse research programs (e.g., McKnight Foundation, Kirkhouse Foundation, N2Africa, PABRA, etc.).

This final meeting provided PIs and collaborators with the opportunity to showcase the technical research achievements of their collaborative projects with the Pulse CRSP community through oral and poster presentations. USAID’s Feed the Future Global Food Security Research Strategy was also presented and its implications for future pulse research priorities discussed by participants. External speakers were invited to lead thematic sessions and stimulate thinking on such critical themes as enhancing dietary quality and achieving nutritional outcomes; enhancing pulse productivity through sustainable intensification of smallholder cropping systems; sustainable seed production and dissemination systems; transforming pulse value chains for the benefit of smallholder women farmers; and utilizing tools of modern molecular genetics to position smallholder, pulse-based production systems for climate change. Since this was the final PI meeting before a possible program extension, time was set aside to consider research and capacity building priorities for the coming five years (2013–2017).

Also during the 2012 Global Meeting in Rwanda, the TMAC presented the "Bean/Cowpea and Dry Grain Pulses CRSP Award for Meritorious Achievement" to the following Pulse CRSP researchers. The award recognizes and honors "laudable contributions to research on grain legumes and the development of technologies and policies that benefit smallholder farmers in developing countries."

- Dr. James Scott Beaver, Recinto Universitario de Mayaguez, Universidad de Puerto Rico
- Dr. Juan Carlos Rosas Sotomayor, Escuela Agricola Panamericana—Zamorano, Honduras
- Dr. Ndiaga Cisse, Institut Senegalais Recherches Agricoles (ISRA), Senegal
- Dr. Richard Bernsten, Michigan State University, U.S.A.

Associate Awards

In 2010, the Bureau of Food Security, USAID, Washington, issued an associate award to the Dry Grain Pulses CRSP Leader Award for a three-year project (October 1, 2010, to September 30, 2013) with an obligation of $3,386,907. The title of the project is *Strategic Investment in Rapid Technology Dissemination: Commercialization of Disease Resistant Bean Varieties in Guatemala, Nicaragua, Honduras and Haiti*, branded as the Bean Technology Dissemination (BTD) project. The project addresses the shortage of high quality bean seed of improved varieties, developed with USAID investment through the CRSP, that are available to resource-poor farmers in Guatemala, Nicaragua, Honduras, and Haiti. The objectives of the BTD project, as outlined below, are aligned with the goals of Feed the Future, that is, to increase staple food productivity and total production so as to reduce prices and food insecurity in strategic countries.

BTD Project Objectives

1. To increase agriculture productivity, profitability, and income of farm families
2. To disseminate outputs of agriculture research to reduce vulnerability and to increase the productivity gains of staple crops
3. To increase market access in an improved policy environment with greater private sector investment
4. To increase nutritional interventions so as to reduce child mortality and improve nutritional outcomes.

Working with distinct institutions in four different countries has demanded a tailored approach to addressing the needs of diverse bean farmer populations. Seed certification policies and NARS institutional programming and cultures vary from one country to another. The subcontracted partner institutions to implement the BTD project include the Instituto de Ciencia y Tecnología Agrícolas (ICTA) and Servicio Nacional de Extensión Agricola (SNEA) [Guartemala]; the Bean Program at the Escuela Agricola Panamericana-Zamorano and Dirección de Ciencia y Tecnología Agropecuarias (DICTA) [Honduras]; Instituto Nacional de Tecnologias Agricolas (INTA) [Nicaragua]; and the National Seed Service (NSS), the Inter-American Institute for Cooperation in Agriculture (IICA); and the private sector enterprise "Agrotechnique" [Haiti].

The cumulative results of the BTD project through two years are summarized in the following table.

Achievement	FY 2011 Results	FY 2012 Results	Cumulative
Smallholder farmers having received and benefiting from quality seed of improved varieties	23,221	35,470	58,691
Hectares cultivated with the improved bean varieties multiplied and disseminated by BTD partners	5,238	5,773	11,011
Number of producers' organizations partnering in the BTD project	55	204	259
Community Seed Banks (CSB) established (total for Guatemala, Nicaragua, and Honduras)	207	35	242
Number of improved seed varieties disseminated that were developed with support of the Bean/Cowpea and Dry Grain Pulses CRSPs.	11	11	11

Overall, important advances have been documented towards building seed security for grain legumes in the region. The Community Seed Bank model has been demonstrated to be sustainable and effective in providing quality seed to large numbers of resource-poor farmers living in remote communities in Nicaragua. Through the multiplication and effective storage of seed, farmers within a community are assured of access to affordable quality seed to plant their next crop. This seed security directly translates to both household food security and opportunities to generate needed income.

Strategic Partnerships and Activities

The Dry Grain Pulses CRSP has been proactive in creating partnerships with other programs and institutions affiliated with bean growth and development.

a. **USDBC.** The U.S. Dry Bean Council (USDBC) has been a consistent long-term advocate for the Dry Grain Pulses CRSP. Research supported by the Pulse CRSP at U.S. universities is recognized and appreciated for it benefits to strengthening the productivity and competitiveness of the bean industry. Director Irvin Widders serves on the Health and Promotions Committee of US Dry Bean Council, the largest and most active committee of the council, and is invited to participate in industry events. The USDBC also had a voice on the TMAC through the membership of Bob Green (2007–10) and Greg Varner (2010–2013).

b. **CGIAR Grain Legume Program.** The Dry Grain Pulses CRSP has made efforts to strengthened its ties with the CGIAR, especially those scientists and centers that are actively involved in grain legume research: CIAT, IITA, and ICRISAT. Because of shared common research interests and goals as well as a common donor (USAID), it is in the interests of both the CGIAR and the CRSP to coordinate efforts. This relationship can most certainly enhance the effectiveness of the legume programs of both institutions because each has its comparative strengths and unique capacities. The Pulse CRSP and associated universities are academic institutions that can boast of cutting-edge research capacity and access to multidisciplinary expertise that can be brought to bear on development and partnerships with Host Country NARS and universities. Conversely, the CGIAR has extensive staff working on the ground on grain legumes in Africa, Asia, and Latin America; has a mandate for germplasm conservation; and has long-term experience addressing many of the persistent constraints to legume productivity. Through improved coordination of research objectives and activities from commodity, thematic , and geographic perspectives in addition to collaboration, greater research advances that will contribute to development outcomes and impacts are expected.

To this end, ICRISAT invited Dr. Widders to participate in the planning of the CGIAR's Grain Legume Program. As a result, the Dry Grain Pulses CRSP (rebranded the Legume Innovation Lab in 2013) is named as a "Strategic Institutional Partner" in the CG's Grain Legume Program and Dr. Widders serves as an active member of the program's research committee. In a reciprocal manner, Dr. Noel Ellis, director of the CG Grain Legume Program, serves on the TMAC along with one to two additional CGIAR scientists involved in bean or cowpea research.

To operationalize this strategic partnership, CIAT, IITA, and ICRISAT scientists have been always invited to participate in the Dry Grain Pulses CRSP global PI meetings. At the 2012 Rwanda meeting, as many as 15 CGIAR scientists attended and contributed as session speakers and presenters of research posters. In addition, Dr. Widders visited several IARCs and established strong working relationships with director generals and research program heads.

c. **Strategic Research Priority Setting Meetings.** In response to USAID's challenge to the Dry Grain Pulses CRSP, the Management Office sought to provide international research leadership by seeking to set a global research agenda to increase grain legume productivity and improve the nutrition of young children and women, strategic research priorities of USAID under Feed the Future (Feed the Future Global Food Security Research Strategy).

A workshop on *Enhancing Pulse Productivity on Problem Soils by Smallholder Farmers—Challenges and Opportunities* was held at Penn State University, State College Pennsylvania, on August 14–17, 2011. This workshop was cosponsored by the Dry Grain Pulses CRSP, CIAT, IITA, and ICRISAT, with financial support from the Bureau of Food Security, USAID. The goal of the workshop was to formulate recommendations on future research foci to achieve major increases in pulse productivity under edaphic and abiotic stress conditions in smallholder farm settings. More than 50 leading scientists, experts, and stakeholders from both the United States and developing countries with interest in and knowledge of global grain legume production (primarily common bean, cowpea, etc.) participated in the workshop and contributed to the research visioning and priority setting exercise. An Executive Summary was developed with recommendations on future research priorities. The MO considers this workshop a success since it informed USAID's funding of new research initiatives on grain legumes as well as that of the USDA/ARS, the CGIAR, and the Pulse CRSP future planning.

A second meeting (a consultation) on *Enhancing Dietary Quality based on Pulses in Developing Countries* was convened at Michigan State University, East Lansing, Michigan, on December 5 and 6, 2011, with the goal of formulating recommendations on future research to achieve improvements in dietary quality and human nutrition from pulses produced on smallholder farm settings. More than twenty public and private sector scientists, experts, and nutrition/health practitioners from the Untied States and developing countries, with interest in and knowledge of global grain legume production and utilization, participated. A consultation summary document was prepared by the meeting coordinator with recommendations on research priorities to address under nutrition of young children and women of child bearing age in FTF countries. This report was distributed to USAID, USDA, and diverse stakeholders and partners of the Dry Grain Pulses CRSP.

d. **Communications Specialist.** In 2011, the MO hired Dr. Marguerite Halversen as the communications specialist for the Pulse CRSP. Communications and promotion of Pulse CRSP research and training achievements were an area that needed strengthening. The addition of Dr. Halversen to the Pulse CRSP team enabled the MO to publish quality annual *Technical Highlights Reports* in a timely manner; to maintain the currency of the program's website; to prepare program brochures, PowerPoint presentations, and posters; and to develop and publish briefs on technological achievements and impacts of the Dry Grain Pulses CRSP.

Challenges to Program Implementation

a. **Personnel Turnover.** Turnover in personnel presented some continuity challenges to the Management Office. In 2010, Dr. Mywish Maredia stepped down as the deputy director after nearly ten years of outstanding service and leadership to the Pulse CRSP. The decision was motivated by Dr. Maredia's desire to return to a faculty research position and pursue her professional interests in international impact assessment research. The MO, however, was able to negotiate an arrangement by which Dr. Maredia would continue to serve the Pulse CRSP MO as its Impact Assessment Advisor (0.25 FTE).

After an internal competitive search, with the support of the dean of the College of Agriculture and Natural Resources at Michigan State University, Dr. Johannes Brink was appointed the new deputy director. His tenure unfortunately was short-lived. In January 2012, Dr. Cynthia Donovan, assistant professor in the Department of Agricultural Food and Resource Economics at MSU, was appointed as deputy director. Dr. Donovan brings a wealth of international agriculture research and development experience to the position, having worked and lived in numerous countries in sub-Saharan Africa and Latin America. In recent years, Dr. Donovan served as a PI on both Food Security and Pulse CRSP projects through MSU. Her expertise in agricultural economics, marketing, and gender as well as extensive experience in working with numerous USAID country and regional missions in Africa have been a great asset to the Pulse CRSP.

Administrative Opportunities and Achievements

a. **Increase in Authorization.** MSU is extremely grateful to USAID for the increased authorization and obligation of funds in 2009. The additional $5 million in funding allowed the Pulse CRSP to address technical gaps in the program due to insufficient funding for research and impact assessment. These initial technical gaps included research on biological nitrogen fixation in legumes, child nutrition, grain legume value chain development, and assessment of impacts by the Pulse and Bean/Cowpea CRSP projects.

b. **Fixed Price Contracts.** Beginning in 2007, the Pulse CRSP required that subcontracted U.S. Lead Universities of projects establish fixed price contracts with sub-subcontracted host country institutions. The experiences of the Lead Universities and the MO with fixed price contracts have been overwhelmingly positive. Because these contracts are performance based, the contracting institutions can hold host country institutions accountable for services rendered (deliverables). Acceptable deliverables include achievement of research and training milestones and submission of satisfactory reports. Partner host country institutions also prefer fixed price contracts over cost-reimbursable contracts because of improved cash flow during a performance period and less stringent requirements for financial management/accounting. On the other hand, U.S. university contract officers pay very close attention to budgets and justifications for projected costs before awarding a fixed price contract. The MO supports this budgetary scrutiny since it provides an additional review of the annual institutional budget requests and links the budgets with the annual technical workplans.

c. **Program Website.** The MO developed a new and improved website for the Dry Grain Pulses CRSP (www.pulsecrsp.msu.edu), which was designed to be of utility both to participant PIs and affiliate institutions as well as Pulse CRSP stakeholders. (Materials from this site can now be accessed through the Legume Innovation Lab website [www.legumelab.msu.edu] or by contacting the Management Office.) The site provides announcements, highlights, technical achievements and impacts, and annual project workplans and technical reports. Technical briefs prepared by PIs were especially appreciated and downloaded by visitors to the website. The website also provided valuable information on the program to the External Evaluation Team commissioned by USAID and the Review of the CRSPs commissioned by BIFAD.

Successful External Program Evaluation and Approval of Technical Application and Budget for Program Extension (Legume Innovation Lab)

The Bureau of Food Security, USAID, commissioned a five-member external evaluation team (EET) in 2012 to conduct an independent evaluation of both the administrative and technical performance of the Dry Grain Pulses CRSP for 2007–2012. To this end, USAID developed a Scope of Work for the external evaluation and requested that the team visit Michigan State University (the ME institution) and selected partner U.S. universities and host country institutions. The EET's assessment of the program and recommendations would be the basis for a decision by USAID to either terminate or to extend the program for an additional five years.

Following site visits to Burkina Faso, Uganda, Zambia, Iowa State University, and Michigan State University and participation in a regional BTD meeting in Nicaragua, the EET developed a report of its findings, concluding that the ME/MO had provided strong, effective, and knowledgeable technical and administrative leadership in the development and implementation of the Pulse CRSP Leader and Associate Awards and in the subsequent monitoring and evaluation of the subcontracted research, capacity building, and technology dissemination projects. The EET also noted the dedication and fine work of the ME and the excellent function of the TMAC. Of the twelve projects evaluated, seven were judged as excellent or significant in their research output; the remaining five were acknowledged for their strong emphasis on and support of HC activities. BTD was also deemed outstanding in its performance.

The EET recommended that research and development of improved bean and cowpea varieties be continued along with research on gene technologies, and on the genetics, management, and deployment of biological control agents for cowpea pests. They further recommended greater emphasis on research on soil fertility and abiotic constraints to pulse yields as well as work toward understanding the nutritional value and importance of bean and cowpeas in diets.

The main concerns of the EET centered on the aging population of both host country and U.S. pulse researchers and the need to mentor new, early- and mid-career scientists in grain legume research to ensure that bean and cowpea research programs be sustainable and that research activities continue after the Pulse CRSP ends, albeit with other funds.

In conclusion, the EET recommended "the extension of the Dry Grain Pulses CRSP program at funding equal to or greater than the total funding for the 2007 to 2012 period."

On January 3, 2013, prior to the conclusion of the five-year award phase of the Dry Grain Pulses CRSP (September 29, 2012, plus a six month, no-cost extension through March 30, 2012), USAID informed Michigan State University that it intended to extend the Dry Grain Pulses CRSP Leader Award with Associates Cooperative Agreement (AID-EDH-A-00-07-00005) for a period of 4.5 years—to September 29, 2017. In response to USAID's guidance, the Management Office prepared

Technical and Cost Applications for a total projected award of $24.5 million over the 4.5 year period. In March 2013, USAID informed the MO that its program would be extended through September 29, 2017, as the Feed the Future Innovation Lab for Collaborative Research on Grain Legumes (Legume Innovation Lab) and amended its contract with MSU.

Acknowledgements

The Management Office recognizes that the ultimate success and impact of the Dry Grain Pulses CRSP is a direct function of the commitment of university partners to scientific excellence and to achieving the global mission and objectives of the program. The MO extends its thanks to all of its PIs and their affiliate institutions who partnered with the Pulse CRSP. Their dedication and contributions to the development and extension of new technologies and knowledge as well as the training of a new generation of leaders in pulse research and development for the benefit and expansion of pulse value chains and nutritional security in developing countries lies at the success of the program.

BEN HASSANKHANI, 1962 – 2013

The Management Office wishes to acknowledge the passionate and dedicated contributions of Benham (Ben) Hassankhani as the Administrative Officer to the success of both the Bean/Cowpea and Dry Grain Pulses CRSPs. Ben unexpectedly passed away on April 16, 2013, after nearly ten years of service to the programs. For the countless U.S. and host country PIs, institutional financial officers, CRSP directors and administrative officers, TMAC members, and MO and CGA staff at MSU, Ben was more than a colleague. He was a dear and loyal friend who loved his job and reminded us constantly of the importance of improving the livelihoods of the poor and food insecure around the world.

In his more than ten years with the Management Office at MSU, Ben not only administered the subcontracts and finances of the program but was an integral part of day-to-day operations: supervising office staff, amending and obligating funds to subcontracts, ensuring that invoices were paid in a timely manner, assisting PIs with the preparation of annual workplans and budgets, providing regular pipeline and accrual reports to USAID at a moment's notice, organizing global and TMAC meetings, keeping computer systems serviced, and on and on.

Ben developed strong relationships with and endeared himself to the Pulse CRSP's PIs and collaborators, national and international. He was always available to serve them and regularly went above and beyond his responsibilities to assist them in resolving administrative and financial challenges in their projects.

Unquestionably, much of the success of global Bean/Cowpea and Pulse CRSP Principal Investigator meetings must be attributed to Ben. He identified international venues and negotiated hotel and transportation rates so that the meetings would be affordable within the program's limited USAID budget. He personally greeted each meeting participant with a smile as they arrived at the airport and escorted them to the hotel to ensure that they were warmly welcomed. When challenges arose at a host country venue, Ben dealt with them with a grace and fortitude that inspired everyone and earned him everlasting respect and affection.

Everyone in the Dry Grain Pulses CRSP family was stunned by Ben's death. Rarely a day passes without a fond memory of Ben coming to our minds. Most certainly, our lives are better for having known and worked with Ben, and we will miss him and his presence in our lives always.

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