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

FY 2015 Annual Project Technical Progress Report
(October 1, 2014 – September 30, 2015)

Project Code and Title: S01.A4 -Development and implementation of robust molecular markers and genetic improvement of common and tepary beans to increase grain legume production in Central America and Haiti

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I. Abstract of Research and Capacity Strengthening Achievements

Conventional plant breeding techniques and marker-assisted selection were used to develop dry bean cultivars with enhanced levels of disease resistance and greater tolerance to abiotic stresses. During the past few years, the Bean Technology Dissemination project multiplied and distributed seed of improved bean cultivars developed by S01.A4 plant breeders to thousands of farmers in Central America and Haiti. Seed of multiple disease resistant black bean cultivar 'XRAV-40-4' and red mottled bean breeding line PR0737-1 was multiplied in Haiti. The small red cultivar 'Paraisito Mejorado 2- Don Rey' with excellent seed type, disease resistance and abiotic stress tolerance was released in Honduras. The BGYMV and BCMNV resistant black bean line MEN-2201-64ML from Zamorano had superior performance under drought conditions in Haiti, Nicaragua and El Salvador. White bean germplasm lines with BGYMV, BCMNV and rust (*Ur-4, Ur-5 and Ur-11*) resistance were released. Red mottled, cranberry and pinto bean lines with BGYMV and BCMNV resistance are ready for testing in field trials. Black bean breeding lines that combine resistance to BGYMV, BCMNV and bruchids are also ready for field testing. Angular leaf spot isolates from Honduras and Puerto Rico were found to have high levels of virulence. Populations are being developed to identify a molecular marker for the *Bgp-1* gene that confers resistance to pod deformation in the presence of BGYMV. Putative markers for bruchid resistance have been identified. Sources of resistance to BCMNV in tepary bean were identified in a newly developed Tepary Diversity Panel (TDP). Tepary bean populations are under development to increase seed size, improve agronomic traits, and combine disease resistance (BCMNV, rust, common blight). Workshops dealing with bean research techniques and seed production were offered at Zamorano. Héctor Martínez from Guatemala and Iveth Rodríguez from Honduras initiated M.S. degree training at the UPR. Several B.S. degree students have opportunities to work with the bean research program at Zamorano.

II. Project Problem Statement and Justification

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

BCMNV threatens bean production in warmer bean production regions of Central America, the Caribbean and Africa. The recent arrival of BCMNV in the Caribbean made the selection for resistance to this virus a priority breeding objective in Haiti, the Dominican Republic and Puerto Rico. BCMNV is also a serious disease in lowland bean production regions of southeastern Mexico. Collaborative research supported by the Bean/Cowpea and Pulse CRSP resulted in the development and release of black bean cultivars and breeding lines such as DPC-40, XRAV-40-4 and MEN-2201-64ML that combine resistance to BCMNV and BGYMV. Small red bean breeding lines with the same combination of resistances are currently being developed at Zamorano. These BGYMV and BCMNV resistant black and small red bean lines will be available in the event that BCMNV emerges as a threat to bean production in Central America. The availability of small red bean breeding lines with BCMNV resistance will permit the field testing of this seed type in Eastern Africa.

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

The project plans to release in Haiti red mottled, yellow and white bean cultivars with enhanced levels of disease resistance. These seed types are produced in regions in Haiti where the CRSP project has had less impact. This effort is consistent with the FTF 2011-2015 multi-year strategy in Haiti to increase the production of staples such as beans to increase food security. In a previous Pulse CRSP project, Dr. Phil Miklas developed Andean bean breeding lines with resistance to BCMNV and anthracnose that should be useful to Legume Innovation Lab breeding projects in Africa and the Caribbean. Yellow, red mottled and white bean breeding lines having BCMNV resistance will be available for Legume Innovation Lab or Feed the Future projects to test in Eastern Africa.

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

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

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

Bean breeders were early adopters of marker-assisted selection to identify lines with desired combinations of traits. This resulted in increased efficiency in the development of improved breeding lines. There are, however, molecular markers available for a limited number of traits. Others, such as the SAP6 SCAR marker, are only effective in a specific gene pool. Therefore, there is a need to develop new or more robust markers, particularly for traits of economic importance to bean breeding programs in the tropics. Recent advances by the BeanCAP project, led by North Dakota State University, in sequencing the bean genome and the development of a SNP array and GWAS will facilitate the mapping and development of molecular markers for traits of economic importance, while breeder-friendly InDel markers are a broadly applicable technology. The availability of phenotypic data in appropriate populations is a major factor limiting the development of these markers. This Legume Innovation Lab will assist this effort through the development of the populations and information needed to identify improved markers for traits such as the *Ur-11* gene for rust resistance. Dr. Phil McClean at NDSU will lead the collaborative effort to develop improved molecular markers.

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

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

III. Technical Research Progress

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

Development, testing and release of improved bean cultivars

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

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

Trial name	Small red	Small black	Countries
Regional bean adaptation nursery (VIDAC)	64 entries + 2 checks	77 entries + 2 checks	GU, ES, HO, NI, CR, HA
Elite line yield trial (ECAR)	14 entries + 2 checks	14 entries + 2 checks	ES, HO, NI, CR, GU, HA
Regional Rojo de Seda Nursery (VIROS)	52 entries + 2 checks	--	ES,HO, NI, CR
Bean variety validation trial (COVA)	8 + 2 checks		ES, HN
Regional angular leaf spot trial (ERMAN)	24 entries + 2 checks	ES, HO, NI, CR, GU, HA	
Regional web blight trial (ERMUS)	8 entries + 2 checks	ES, HO, CR, GU	
Biofortified bean trial (AGROSALUD)	9 entries + 1 check	ES, HO, NI, GU, CR	
Regional BNF trial (ERFBN)	8 entries + 2 checks	HO	
Regional high temperature trial (ERSAT)	20 entries + 5 checks	HO, CR	
Regional drought trial (ERSEQ)	20 entries + 5 checks	HO, CR	
Tepary bean adaptation trial (TAT)	19 + 1 check	HO, CR	
Regional tepary bean trial (ERTEPARI)	21 entries + 1 check	CR, HO	

Greater tolerance to abiotic stress

Although disease resistance is the primary focus of this Legume Innovation Lab project, the performance of bean breeding lines is evaluated in low fertility soils. Honduras has an ideal site for the evaluation of lines for adaptation to low P soils. Puerto Rico has good locations for screening beans for performance in a low N soil, root rot resistance and high temperature. These sites will be used to evaluate the performance of bean breeding lines derived from recurrent selection for increased BNF and/or selected for greater nitrogen use efficiency. These sites will be inoculated with efficient *Rhizobium* strains to allow indirect selection for enhanced BNF.

Bruchid resistance

Bruchid resistant bean breeding lines developed by Dr. Kusolwa at Sokoine University of Agriculture have been used to introgress resistance to this pest into commercial seed types (black, small red, red mottled, light red kidney and yellow) produced in the target countries. A laboratory screening technique developed at the University of Puerto Rico has been used to evaluate the resistance of bean breeding lines. The effectiveness of using molecular markers for traits (null phaseolin, arcelin 2 and APA locus) associated with bruchid resistance is under evaluation. An additional breeding objective is to combine bruchid and virus (BCMV, BCMNV and BGYMV) resistance. Bruchid resistant 'Rojo' backcross lines developed in collaboration with Jim Myers (Oregon State University) and Paul Kusolwa (Sokoine University of Agriculture) were identified to also have BCMV and BCMNV (I + $bc\text{-}1^2$) resistance. Considerable progress has also been made toward the development of black beans that combine bruchid and virus resistance.

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

The Middle American (MDP) and Andean Diversity (ADP) panels will be screened in Central America and the Caribbean for specific traits. For example, the Andean Diversity Panel will be screened in Haiti for reaction to powdery mildew and in Honduras for angular leaf spot. Performance of the Middle American Diversity Panel will be evaluated in low N environments in Central America and the Caribbean. The Middle American Diversity Panel has been screened in Puerto Rico for resistance to ashy stem blight.

Genetic Improvement of Tepary Beans

Although tepary bean has high levels of abiotic stress tolerance, it is susceptible to viruses such as BGYMV, BCMV, and BCMNV. In order to expand the potential use of tepary bean in abiotic stress prone regions, a primary focus of this project will be to incorporate newly identified resistance in tepary accessions into tepary breeding lines, and to initiate the introgression of virus resistance from common bean into tepary bean. By project end (FY17) we expect to have tepary breeding lines with improved virus resistance that will be available for pyramiding of virus resistance loci in future efforts. A tepary breeding program was initiated at USDA-ARS-TARS in 2008. Advanced breeding lines developed from these previous breeding efforts have been increased and shared with the collaborators for testing in Tepary Adaptation Trials (TAT). New tepary breeding lines have been generated from crosses between promising large and round seeded genotypes from the CIAT collection and breeding lines selected for disease and abiotic stress tolerance. Using leveraged funds, these materials were initially tested through a shuttle breeding program with M. Brick at Colorado State University. This effort will focus on seed size/shape, drought and heat tolerance, and CBB and bruchid resistance in PR; and on photoperiod insensitivity, broad adaptation, rust resistance, and yield in Colorado. Superior lines will then be tested in the host countries for potential future release.

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

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

Identify genetic materials for marker evaluation

Potential targets for improved marker development include:

- Bean golden yellow mosaic virus resistance genes and QTL (*bgm*, SW12, *Bgp*)
- Bruchid resistance genes (*Arc2, Arl3, PHA* and *aAI3*)
- BCMV and BCMNV (*I, bc-3,* $bc\text{-}1^2$)
- Bean rust (*Ur-4, Ur-5, Ur-11*).

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

Development of InDel markers

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

Objective 3. Institutional capacity building

Formal and informal training activities will be conducted to enhance the capacity of host country bean research programs to develop and release superior-performing bean cultivars that will increase production or reduce losses in the target countries. At the end of this project, these bean research programs should have the capacity to utilize the newly-developed suite of InDel markers for marker-assisted selection. The Ph.D. and M.S. degree students will be provided a broad range of training in conventional and molecular plant breeding techniques so that they can assume roles of leadership in bean research programs in the target countries. Informal training of technicians should improve the reliability and quality of bean research conducted in host countries.

Informal training

- In-service training will be provided during FY16 at NDSU for Legume Innovation Laboratory scientists to review recent advances in sequencing the bean genome and the utilization of SNP arrays to develop InDel markers for traits of economic importance.
- A workshop was held in Honduras in April 2015 to train technical personnel from Central America and the Caribbean concerning bean research techniques with the goal of improving the quality of field research. Topics included the development and management of field trials, breeding and selection methods, field evaluation techniques, research with Rhizobium, participatory plant breeding and agro-ecological techniques.
- The project received Institutional Building Funds to conduct a workshop at Zamorano in August 2015 to discuss with technical personnel from Central America and the Caribbean techniques needed to produce, process and store high quality seed stocks. The training should improve the capacity of the bean research programs in Central America and Haiti to produce basic and foundation seed stocks of recently-released bean cultivars.
- A significant amount of information concerning bean research techniques is already available on the Bean Improvement Cooperative (BIC) web site http://bic.css.msu.edu/ResearchTechniques.cfm. This Legume Innovation Lab project will collaborate with the BIC in developing modules for the BIC web site that will describe research techniques for additional traits such as bruchid resistance.

IV. Major Achievements

Development, testing and release of improved bean cultivars

- XRAV-40-4, a multiple disease resistant black bean adapted to the humid tropics, was developed and released cooperatively by the Puerto Rico (UPR) and Nebraska (UNL) Agricultural Experiment Stations, the USDA-ARS, the Instituto Dominicano de Investigaciones Agropecuarias y Forestales (IDIAF), the Escuela Agrícola Panamericana, Zamorano, Honduras, and the National Seed Service of the Ministry of Agriculture of the Republic of Haiti. 'XRAV-40-4' combines resistance to BGYMV, BCMV, and BCMNV. When planted at higher altitudes, XRAV-40-4 has earlier maturity than the black bean cultivar 'DPC-40'. A description of the release of XRAV-40 was published in the J. of Agric. of the Univ. of Puerto Rico (Beaver *et al*., 2014. JAUPR. 98:83-87). XRAV-40-4 is expected to be released in Central America as 'Azabache 40' and in Haiti as 'Sankara'. XRAV-40-4 performed well in on-farm trials conducted by the NSS with support from FAO.

- The cultivar “Paraisito Mejorado 2- Don Rey” was released in Honduras. This cultivar has a light red seed color similar to its landrace parent “Paraisito” but carries the BGYMV and BCMV disease resistance and greater adaptation to low soil fertility from its recurrent parent, the improved bean cultivar Carrizalito.
- White bean lines were released that combine the *bgm-1* gene and the SW12 *QTL* for resistance to BGYMV, the *I* and *bc-3* genes for resistance to BCMV and BCMNV and resistance to a wide range of rust races. Results from inoculations with specific races of rust conducted by Dr. Pastor-Corrales, USDA-ARS-Beltsville suggest that the white bean lines have a unique combination of the *Ur-4, Ur-5* and *Ur-11* rust resistance genes. A manuscript describing the release of these bean breeding lines as germplasm releases was published in the *J. Plant Registrations* (Beaver *et al.*, 2015. *J. Plant Reg*. 9:208-211). This was the first release of improved bean germplasm that combines multiple virus (BGYMV, BCMNV and BCMV) and rust resistance. An elite white bean nursery will be distributed by Dr. Juan Carlos Rosas to collaborators in Central America and the Caribbean.
- These rust resistant white bean breeding lines were used as parents to introgress high levels of rust resistance into black beans. DPC-40 and XRAV-40-4 were used as parents to insure that progeny from these crosses will also have multiple virus resistance. F_5 black bean lines with good agronomic type were selected from these populations. These lines will be screened during second growing season of 2015 at Zamorano for resistance to rust. Previous research has found rust races in Honduras to have high levels of virulence. Dr. Pastor-Corrales (USDA FtF project collaborator) will conduct greenhouse evaluations of lines that are rust resistant in field trials in Honduras. This effort should lead to the development of black bean lines that combine multiple virus resistance and the *Ur-4, Ur-5* and *Ur-11* rust resistance genes. The most promising lines will be included as entries in regional performance trials for Central America and the Caribbean.
- The red mottled bean line PR0737-1 that combines the *bgm-1* allele for resistance to BGYMV and the *I* and *bc-3* alleles for resistance to BCMV and BCMNV, was released as improved germplasm (Prophete *et al*. 2014. *J. Plant Reg.* 8:49-52). Seed of PR0737-1 is currently being multiplied in Haiti and is in the process of being formally released as a cultivar.
- Yellow bean lines that combine the *bgm-1* gene for resistance to BGYMV and the *I* gene for resistance to BCMV were developed and tested in Puerto Rico, Angola and Haiti. One of the lines, PR1146-138, also expressed tolerance to leafhoppers in a trial planted in Damien, Haiti in 2014 and produced a mean seed yield of 1,884 kg/ha over seven environments. Seed of this line has been multiplied for on-farm trials that will be conducted in Haiti during FY16. A manuscript describing the release of PR1146-138 has been submitted to the *J. Plant Reg.*
- An advanced generation yellow bean breeding line, PR1501-162 with good agronomic traits and commercial seed was screened using molecular markers and found to combine the *bgm*-1 allele and the SW12 QTL for resistance to BGYMV, the *I* allele that confers resistance BCMV and the SAP6 QTL for resistance to common bacterial blight. The performance of this line will be evaluated in Haiti and Puerto Rico during the upcoming year.
- Pinto beans gained popularity in Haiti after this market class was imported as food aid. Consumers note that pinto beans have a shorter cooking time than other seed types used in Haiti. During the past year, we multiplied seed of advanced generation lines that have the *bgm-1* allele and the SW12 QTL for BGYMV resistance and the *I* and *bc-3* alleles for resistance to BCMV and BCMNV. All of the lines have commercial pinto seed type and many have an erect growth habit. During the upcoming year, these lines will be evaluated in trials in Haiti, Honduras and Puerto Rico. These pinto lines should segregate for the *Ur-11* gene so

special attention will be given to lines that do not develop rust symptoms. Two generations will be planted in Puerto Rico during FY16 to multiply seed of the most promising lines. Because Durango race beans have performed well in Eastern Africa, the pinto lines were sent to Dr. Phil Miklas for evaluation in Tanzania.

- The performance of red mottled and cranberry bean lines with commercial seed type and resistance to BGYMV, BCMV and BCMNV will be evaluated in Puerto Rico and Haiti during the upcoming year. Seed of these lines were also sent to Dr. Karen Cichy for evaluation in Michigan and Africa.
- Determinate black bean lines with resistance to BGYMV, BCMV and BCMNV were selected. There lines are very early in maturity which may help to avoid terminal drought. The performance of these lines will be tested in Honduras, Haiti and Guatemala during the upcoming year.
- Advanced generation black bean lines from Puerto Rico that were identified to possess the *bgm-1* gene for resistance to BGYMV and the *I* and *bc-3* genes for resistance to BCMV and BCMNV were tested in Haiti, Guatemala and Puerto Rico. Many of these lines have progenitors with heat tolerance and resistance to common bacterial blight and web blight. These lines expressed little damage from leafhoppers in Damien, Haiti and Jutiapa, Guatemala although many bean lines in neighboring trials were severely damaged. Black bean lines with resistance to BGYMV, BCMV, BCMNV and rust were selected for in San Jerónimo, Guatemala by ICTA researchers.
- 'Beseba' is a Haitian Lima bean from a collection made by the Dry Grain Pulse CRSP and sent to CIAT to be included in the germplasm collection. Dr. Rao, CIAT Physiologist, reported at the 2014 PCCMCA meeting in Nicaragua that 'Beseba' (G 27529) produced the greatest seed yield in a high temperature trial conducted in Colombia. Emmalea Ernest reported at the 2014 BIC meeting that G 27529 had among the greatest amount of pollen shed in a high temperature trial conducted in Delaware (BIC 57:41-42). Heat tolerant Lima beans should be tested as an alternate crop for the dry corridors of Honduras, El Salvador and Guatemala. The CIAT Lima bean germplasm collection should be screened for reaction to BGYMV to attempt to identify a potential source of resistance.
- IICA personnel reported that the black bean variety ICTAZAM, that has a shiny seed coat, is acceptable to consumers in Guatemala. ICTAZAM has resistance to BGYMV, BCMV and web blight and was identified by ICTA researchers to have superior performance in more humid regions such as the Petén region of Guatemala.

Greater tolerance to abiotic stress

- INTA and CENTA researchers reported that the black bean line MEN-2201-64ML from Zamorano had superior performance under drought conditions in Nicaragua and El Salvador. This line was also selected for further evaluation in Haiti based on its performance during the dry season. In addition to drought tolerance, MEN-2201-64ML was selected for resistance to BCMV, BCMNV and BGYMV. During the upcoming year, this Legume Innovation Lab project will support the on-farm testing of MEN-2201-64ML in Haiti, Honduras, Guatemala and other Central American countries where drought is a frequent constraint to bean production. The NSS in Haiti multiplied seed of this line during the summer of 2015 to distribute to farmer groups in November.
- The small red bean breeding line IBC-301-204, selected at Zamorano for resistance to BGYMV, BCMV and tolerance to low fertility trials, was released in Nicaragua as INTA Centro Sur.

- The small red bean breeding line SJC 730-79, selected at Zamorano for resistance to BGYMV, BCMV and tolerance to high temperatures, will be released by CENTA in El Salvador.
- Small red and black breeding lines were selected at Zamorano from the second cycle of recurrent selection having greater nodulation, plant growth, seed yield, and resistance to BCMV and BGYMV. The most promising lines were distributed to collaborators in Central America for field evaluation in diverse conditions. Greater nodulation in the low N field (0.08 % N), soil: sand benches (0.06% N) and plastic pouches (nodulation speed) was obtained with *Rhizobium tropici* (CIAT 899) and *R. etli* (CIAT 632).
- In collaboration with USDA-ARS FtF, 134 lines from the Andean Diversity Panel were evaluated for nodulation characteristics in pasteurized sand inoculated with *Rhizobium tropici* strain CIAT 899 and *Rhizobium etli* CIAT 632 separately. Twelve days after inoculation lines ADP-186, -225, -302, -368, -390, -444, -456, -477 and -514 were selected for early nodulation and greater nodule number.

Bruchid resistance

- Rojo' backcross lines were selected in collaboration with Paul Kulsolwa at Sokoine University and Jim Myers at Oregon State University that combine resistance to bruchids [*Acanthoscelides obtectus* (Say)] and the *I* and $bc\text{-}1^2$ genes that confer resistance to BCMV and BCMNV. AO-1012-29-3-3A yielded as well as USLK-1 and 'Badillo' in trials conducted in Puerto Rico. This breeding will be considered for release as improved germplasm.
- The 'Rojo' backcross lines were used as parents to develop Andean and Middle American lines with bruchid resistance. Black and bean lines were developed that combine resistance to bruchids, the *bgm-1* gene for resistance to BGYMV and the *I* and *bc-3* genes for resistance to BCMV and BCMNV. Seed of bruchid resistant black bean lines were sent to Honduras, Guatemala and Haiti where they will be evaluated for adaptation and for resistance to local eco-types of bruchids.
- Many lines selected for bruchid resistance were found to possess the molecular markers developed by Dr. Paul Kusolwa for alpha amylase and phyto-haemagglutinin. These markers, however, did not account for all of the phenotypic variability associated with the bruchid resistance. One of the parents of the 'Rojo' backcross lines has the recessive null phaseolin allele. We are exploring, in collaboration with the USDA-ARS FtF project and Dr. Jim Myers, the possibility that the null phaseolin trait may contribute to bruchid resistance.
- As part of B.S. degree theses research projects at Zamorano, students will evaluate lines selected in Puerto Rico for bruchid resistance. The lines will be infested with Honduran ecotypes of *A. obtectus* and *Zabrotes subfasciatus* (the Mexican bean weevil). Results from this research will help to confirm that the bruchid resistance will be effective over a broad geographical region and will suppress the development of both of the genera of bruchids that can cause major post-harvest losses in Central America and the Caribbean. Preliminary results indicate that the lines selected for resistance to *A. obtectus* are also resistant to *Z. subfasciatus*.

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

- Project personnel were co-authors in a paper published in *Crop Science* entitled "A *Phaseolus vulgaris* Diversity Panel for Andean Bean Improvement" (Cichy et al. 2015, *Crop Sci*. 55: 2149-2160). Legume Innovation Lab project S01.A4 contributed lines to the ADP and collaborated in the evaluation of the ADP for several traits of economic importance.

- The Andean Diversity Panel was screened in the greenhouse at the UPR for resistance to powdery mildew. Although none of the Andean lines were immune to powdery mildew, we did observe differences among lines in severity of infection. We made individual plants selections at the Isabela Substation in an Andean bean population that appeared to segregate for resistance to powdery mildew. The lines will be screened in the greenhouse during the upcoming year for reaction to the disease.
- The virulence patterns of *Pseudocercospora griseola* isolates from Honduras and Puerto Rico were studied. One isolate from Honduras was virulent to all of the ALS differential lines (race 63-63). The most virulent isolate from Juana Díaz Puerto Rico was race 63:39. This high level of virulence points to the need to pyramid genes for ALS resistance. Molecular markers SH-13 (*Phg-1*), SN02 (*Phg-2*) and E-ACA/M-CTT330 (G10474 dominant gene) were used at Zamorano for marker-assisted selection. Resistance in the field was confirmed using highly virulent races of the ALS pathogen. During the upcoming year, a small red bean line (ALS 0532-6) and a black bean line (ALS 0546-60) that combine resistance to multiple viruses (BGYMV and BCMV), high yield potential and commercially acceptable seed type will be evaluated in validation trials in Central America. ALS resistant white bean breeding lines were developed for Puerto Rico using sources of resistance from Zamorano.
- The National Seed Service in Haiti plans to screen in the field the Andean Diversity Panel for reaction to powdery mildew. Results will be used to conduct an associated mapping analysis for reaction to *Erysiphe polygoni* in the Andean gene pool.
- In collaboration with the USDA-ARS FtF project, association mapping of the response to *Macrophomina phaseolina* in the Andean Diversity Panel was conducted. Results from field screening identified a small group of lines in the ADP with resistance to ashy stem blight. Regions on Pv03, Pv09, and Pv11 were significant for charcoal rot resistance in the association mapping analysis.
- Isolates from a root rot nursery in Isabela were identified as *Rhizoctonia solani* (Rs), *Fusarium solani* (Fs) and *Pythium ultimum* (Pu). Inoculation tests were conducted with each fungal pathogen. Interspecific line INB 835 and TARS-LFR1 were found to be resistant to Rs. ADP 518, ADP 508 and ADP 475 were the Andean bean lines with the highest levels of resistance to Rs. Tepary beans inoculated with Fs did not develop symptoms. In contrast, common beans showed reddish lesions on the hypocotyl and browning of the tap root. The lines ADP 475, ADP 518, ADP 269 and LFR-1 had only small reddish lesions on the hypocotyl (disease scores ≤ 3). These results suggest that Rs and Fs independently produced hypocotyl and root rots.
- The Mesoamerican Diversity Panel (MDP) and a set of the Andean Diversity Panel (ADP), resistant to ALS in South Africa, were evaluated for their response to ALS in a trial at Zamorano, HN in collaboration with the FtF-USDA project. Resistant genotypes were identified for breeding efforts in both panels.
- In an attempt to identify a set differential genotypes for *Macrophomina phaseolina* (Mp), a screenhouse trial was established to evaluate the response of common bean, tepary and and intespecific (common bean x tepary bean) bean lines to Mp isolate Mph-01-JD. TARS-MST1, DOR-364 and BAT 477 were resistant to the isolate.

Genetic Improvement of Tepary Beans

- Release of tepary bean selection Tep-22 that combines resistance to common bacterial blight, rust and tolerance to heat and drought (Porch et al. 2013. J. Plant Reg. 7:358-364).

- Tepary bean breeding lines have been developed that should combine virus resistance with superior agronomic and seed traits and resistance to other diseases such as common bacterial blight and rust.
- In collaboration with the USDA-ARS FtF project, UPR graduate student Ana Vargas identified tepary bean germplasm accessions that show necrotic and resistant reactions when inoculated with the NL-3 isolate of BCMNV. BCMV and BCMNV are currently major constraints to tepary bean production.
- Recombinant Inbred Line (RIL) populations are under development to identify genes and molecular markers for this resistance. One of these RIL populations showing a necrotic response to NL3 inoculation is being genotyped using Genotyping-by-sequencing (GBS), phenotyped using visual scoring and ELISA, and QTL analysis will subsequently be completed.
- Putative early generation interspecific lines for combining BGYMV and BCMNV resistance from common bean with tepary bean have been developed and are being advanced for the evaluation of effective hybridization and for virus resistance.
- Tepary adaptation trials have been conducted in Honduras, Nicaragua, El Salvador, and Burkhina Faso.
- Through the USDA-FtF project and a USDA Postdoc, the Tepary Diversity Panel (TDP) composed of 320 accessions was developed and genotyped. The panel represents all currently available tepary accessions between the USDA and CIAT collections. This panel is being evaluated for a number of different traits including morphology, BNF, and response to NL3 inoculation.
- In collaboration with USDA-ARS FtF project, 12 Interspecific hybrid *Phaseolus acutifolius/Phaseolus vulgaris* INB lines were evaluated in a replicated field trial with inoculation of *Bradyrhizobium* USDA 3254. A non-inoculated control and Nitrogen treatments were included. In addition to that a local check “Verano”, TARS-LFR1 and a non nodulator line “G51496A” were inoculated with *Rhizobium tropici* CIAT 899 strain. An average of 25 nodules were recorded for line INB 835 and six nodules for line INB 826. The average for line Tepary 1 was 1.5 nodules and for TARS-LFR1 26 nodules.
- Interspecific hybrids between the common bean (*Phaseolus vulgaris* L.) and the tepary bean (*Phaseolus acutifolius* A. Gray) were nodulated by different rhizobia; the slow growing *Bradyrhizobium* sp. and the fast growing *Rhizobium* spp. Elite strains of *Bradyrhizobium* (USDA 3254) and *Rhizobium tropici* (CIAT 899) were studied in their ability to nodule effectively in interspecific hybrids. The experiment was arranged in a split plot design with inoculation of the combination of both strains, a control without inoculation and a NPK treatment in the main plot. The small plot consisted of common beans: “Verano”, LFR-1, tepary bean Tep 23, Tep 32 and the Interspecific hybrids: INB-817, INB-848, INB 817 and INB-835. The experiment was established in Juana Diaz with a population of 1 x 10^2 *Bradyrhizobium* and 1 x 10^4 *Rhizobium* per gram of soil. The experiment was replicated four times. Six weeks after sowing nodulation and plant biomass were evaluated and at maturity seed grain yield was measured. Ten nodules were isolated in Yeast-Mannitol-Agar with bromotymol blue from each treatment to differentiate bradyrhizobia and rhizobia base on growth rate and acid production. The hybrids and the common beans differed in nodule numbers from the tepary beans. More than 90 percent of the nodules that were isolated from the hybrids resulted in a fast growing rhizobia. In contrast from the tepary beans nodules the isolations were from a slow growing bradyrhizobia. The lines LFR-1, INB-809 and INB-826 were outstanding in nodule numbers. All genotypes were different from the tepary beans in nodulation. INB-809 was superior in nodulation followed by LFR-1, Verano

and INB-826, INB-835, INB-848 and INB-817. The inoculated treatment was different from the NPK and the control in nodule numbers independently of the presence of soil rhizobia. Root dry weight was higher for INB-809 and LFR-1 comparing to the other genotypes. Grain weight differences among treatments suggested that inoculation increased seed yield and INB-817 was superior to the other genotypes. The nodules isolated in media produced fast growing rhizobia and produced acidity in the media that was consistent with the cultural characteristics of *Rhizobium tropici.*

Development of InDel markers

- Populations are under development at Zamorano that segregate for the dominant gene *Bgp-1* that confers resistance to pod deformation in the presence of BGYMV. RILs will be phenotyped at Zamorano for pod deformation and the data will be used by Dr. Phil McClean to attempt to identify a molecular marker for this important gene for resistance to BGYMV.
- Lines selected for resistance to bruchids was sent to Dr. Phil McClean to identify candidate markers for resistance genes. They have screened ~20 markers across the APA locus on Pv04. The majority of these are InDel markers. They supplemented the InDel markers with a few SSRs that have been reported in the literature. Two putative markers have been identified at NDSU. The candidate markers will be tested to determine their effectiveness to identify lines with resistance.

V. Research Capacity Strengthening

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

The project received Institutional Strengthening Funds to continue to support the bean research network in Central America and the Caribbean. These funds permit bean researchers in the region to attend the annual meeting of the PCCMCA where research results can be shared. The PCCMCA meeting also provides an opportunity for Legume Innovation Lab and CIAT scientists to meet with bean researchers to plan collaboration for the upcoming year. During the upcoming year the project will collaborate with INTA to commemorate the International Year of the Pulse at the PCCMCA meeting in Costa Rica.

This Legume Innovation Lab project continues to collaborate with many CRSP alumni institutions. This collaboration extends the potential impact of Legume Innovation Lab research and generates information that is valuable to the global bean research community. A few of the collaborative research activities are listed below:

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

VI. Human Resource and Institution Capacity Development

1. Short-Term Training

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

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

2. Degree Training

Table 3. Summary of degree training of Legume Innovation Lab project S01.A4 during FY15.

Name of trainee	Héctor Martínez	Iveth Rodríguez	Diego Rodríguez	Julian Colley Pabón	Ian Pizarro	Jason Rizo	Johan Gabor	José Martinez	Luis Peñate	Luis Monserrate	Henry Espinoza	Juan Nuñez	Carlos Maldonado	Lucy Lund
Country of citizenship	Guatemala	Honduras	Ecuador	Puerto Rico	Ecuador	Nicaragua	Ecuador	El Salvador	El Salvador	Ecuador	Ecuador	Honduras	Guatemala	U.S.
Gender	M	F	M	M	M	M	M	M	M	M	M	M	M	F
H.C. institution	ICTA	Zamorano	INIAP	None	None	None	None	None	None	None	None	None	ICTA	None
Training institution	UPR	UPR	UPR	UPR	Zamorano	Zamorano	Zamorano	Zamorano	Zamorano	Zamorano	Zamorano	Zamorano	NDSU	NDSU
Supervising CRSP PI	J.S. Beaver	J.S. Beaver	J.S. Beaver	C. Estevez	J.C. Rosas	J.C. Rosas	J.C. Rosas	J.C. Rosas	J.C. Rosas	J.C. Rosas	J.C. Rosas	J.C. Rosas	Juan Osorno	Phil McClean
Degree program	M.S.	M.S.	M.S.	M.S.	B.S	B.S	B.S	B.S	B.S	B.S	B.S	B.S	M.S.	M.S.
Field or discipline	Plant breeding	Plant breeding	Plant breeding	Plant Pathology	Plant Science	Plant Science	Plant Science	Plant Science	Plant Science	Plant Science	Plant Science	Plant Science	Plant breeding	Plant genomics
Research project title	Web blight resistance	Drought-heat tolerance	ALS resistance	Ashy stem blight resistance	Bruchid resistance	Low fertility tolerance	Low fertility tolerance	Races of P. griseola	Races of P. griseola	Resistance to ALS	Resistance to ALS	BNF	Resistance to anthracnose	Mol. genetics res. to bruchids
Start date	Aug. 2015	Aug. 2015	Aug. 2015	Jan. 2015	May 2015	May 2015	May 2015	May 2015	May 2015	May 2015	May 2015	May 2015	Aug. 2015	July 2015
Completion date	Jul. 2017	Jul. 2017	Jul. 2017	Dec. 2017	Nov. 2015	Nov. 2015	Nov. 2015	Nov. 2015	Nov. 2015	Nov. 2015	Nov. 2015	Nov. 2015	Dec. 2017	June 2017
Participant trainee and registered on TraiNet?	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	No

VII. Achievement of Gender Equity Goals

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

VIII. Achievement and Progress along the Impact Pathway

Central America

Since the majority of bean improved cultivars used in Central America were developed with support from the Legume Innovation Lab, Zamorano continues to be the main source of genetic and foundation seed for the national research institutions, national seed systems, NGOs and farmer organizations. A bean seed production workshop was held at Zamorano in August 2015 to promote the production of breeder and basic seed.

Under the Bean Dissemination Project (2010-13) nearly 27,000 farmers received high quality seed of improved bean cultivars in Honduras, and Zamorano provide foundation seed and Rhizobium inoculant to INTA/Nicaragua, ICTA/Guatemala and NSS/Haiti. In Honduras, several Local Agricultural Research Committees (CIALs), which were involved in this project, continue producing seed using registered seed provided by Zamorano.

Under a similar approach, Zamorano continues to provide foundation seed of improved bean cultivars and *Rhizobium* inoculant to the bean technology dissemination project coordinated by MSU in collaboration with Technoserve and DICTA in Honduras.

Haiti

During the summer of 2015, the National Seed Service produced of seed of the multiple disease resistant black bean varieties 'XRAV-40-4', 'DPC-40' and MEN2201-64ML and the red mottled bean PR0737-1. The stationary thresher, purchased with funds from the Pulse CRSP, facilitated the harvest at Savane Zombi and generated interest among bean growers. Project funds will be used to improve seed storage facilities at Savane Zombi. Dry weather during the summer reduced seed yields.

Former collaborators in the Bean Technology Dissemination project continued to produce a significant amount of seed of improved bean cultivars in Haiti during 2015. The NGOs Zanmi Agrikol and Hands Together produced seed of DPC-40 during 2015. This seed was sold to small-scale farmers in the Central Plateau and Gonaives.

IX. Explanation for Changes

- The formal training of Carl Didier Joseph from Haiti was postponed until January 2016. This was due to delays in obtaining documents needed for admission to the UPR.
- A second year of drought during the first growing season in Central America and the Caribbean significantly reduced bean yield and caused a severe shortage of seed for the second growing season. During the upcoming year, Zamorano and other bean research programs in Central America will need to increase the production of basic seed to replenish stocks for the 2016 growing seasons.

X. Self-Evaluation and Lessons-Learned

- The USAID TraiNet system and the requirement for Legume Innovation Lab trainees to have J-1 visas is time-consuming and complex. In addition, it also limits opportunities to match Legume Innovation lab funding with other sources of funding for training.
- The second year of drought in Central America and the resulting shortage of bean seed during the second growing season highlights the vulnerability of the seed production system in the region. There may be opportunities for bean seed producers in the U.S. to serve as an alternative source of seed during years when there are shortages in Central America and the Caribbean. Dr. Phil Miklas has demonstrated that small red cultivars such as 'Amadeus 77', 'CENTA Pipil' and 'DEORHO' and black bean cultivars such as 'Aifi Wuriti' and 'DPC-40' produce good seed yields in Prosser, Washington. During the past year, Dr. Porch was invited by the PASA project in Haiti to submit a proposal to increase bean production in Haiti. One of the key components in the proposal is the production of high quality, genetically pure black bean seed in the Western U.S. during the summer months. An initial increase of the black bean cultivar 'Sankara' (XRAV-40-4) was successful.
- Bean cultivars initially selected for specific traits using marker-assisted selection need to be monitored for genetic purity. It has been necessary to re-select seed of Aifi Wuriti and PR1146-138 to insure the presence of the *bgm-1* allele for BGYMV resistance.

XI. Scholarly Accomplishments

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

Beaver, J.S., E.H. Prophete, J.C. Rosas, G. Godoy Lutz, J.R. Steadman and T.G. Porch. 2014. Release of 'XRAV-40-4' black bean (*Phaseolus vulgaris* L.) cultivar. J. Agric. of the Univ. of Puerto Rico 98:83-87.

Beaver, J.S., Prophete, E., Demóstenes, G. and T.G. Porch. 2015. Desarrollo de la Línea de Frijol Amarillo PR1146-138. Paper presented at the 2015 meeting of the PCCMCA held in Guatemala City from 4 to 7 May 2015.

Bello, M. H., S. M. Moghaddam, M. Massoudi, P. E. McClean, P. B. Cregan, and P. N. Miklas. 2014. Application of in silico bulked segregant analysis for rapid development of markers linked to *Bean common mosaic virus* resistance in common bean. BMC Genomics 15:903

Buruchara, R., Estévez de Jensen, C., Godoy G., Abawi G., Pasche J., Lobo J. and Mukankusi, C. 2015. A review of the root rot diseases of common bean with emphasis in Latin America and Africa. Presentation at the Common Bean Disease Workshop on Angular Leaf Spot and Root Rot held in Skukuza, South Africa from 20 to 23 July 2015.

Chilagane, L.A, S.N Msolla, T. Porch & L.M. Serrato-Diaz. 2015. Towards genetic characterization of *Pseudocercospora griseola*, the causative agent of angular leaf spot of common bean in Tanzania. Presentation at the Common Bean Disease Workshop on Angular Leaf Spot and Root Rot held in Skukuza, South Africa from 20 to 23 July 2015.

Cichy, K.A., T.G. Porch, J.S. Beaver, P. Cregan, D. Fourie, R. Glahn, M.A. Grusak, K. Kamfwa, D.N. Katuuramu, P. McClean, E. Mndolwa, S. Nchimbi-Msolla, M.A. Pastor-Corrales and P.N. Miklas. 2015. A *Phaseolus vulgaris* diversity panel for Andean bean improvement. Crop Sci. 55:2149-2160.

Estévez de Jensen, C., Porch, T.G. and J.S. Beaver. 2015. Evaluación de híbridos interespecíficos de fréjol tépari x fréjol común con inoculación de Bradyrhizobium y Rhizobium. Paper presented at the 2015 meeting of the PCCMCA held in Guatemala City from 4 to 7 May 2015.

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Kusolwa, P.M., M.W. Mwatawala, S.N. Msolla, G. Kananji, G.M. Tryphone, J.R. Myers & J.S. Beaver. 2015. Breeding for bruchid resistance into farmers' preferred common bean (*P. vulgaris*) varieties: Developments and Challenges. Presentation at the Common Bean Disease Workshop on Angular Leaf Spot and Root Rot held in Skukuza, South Africa from 20 to 23 July 2015.

Porch, T.G., S. Valentin, C. Estevez de Jensen and J.S. Beaver. 2014. Identification of soil-borne pathogens in a common bean root rot nursery in Isabela, Puerto Rico. 2014. J. of Agric. of the Univ. of Puerto Rico. 98:1-14.

Porch, T.G, Hart, J., Vargas, A., Brick, M and J.S. Beaver. 2015. Caracterización de un panel de frijol tépari (*Phaseolus acutifolius*) y su aplicación en mejoramiento de este cultivo huérfano. Paper presented at the 2015 meeting of the PCCMCA held in Guatemala City from 4 to 7 May 2015.

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Prophete, E., G. Demosthenes, G. Godoy-Lutz, T.G. Porch, and J.S. Beaver. 2014. Registration of PR0633-10 and PR0737-1 red mottled dry bean germplasm lines with resistance to BGYMV, BCMV, BCMNV, and common bacterial blight. J. Plant Reg. 8:49-52.

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

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

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

Vásquez J., Estévez de Jensen C., Ghising, K., VanderWal, M., Kloberdanz M. and Osorno J.M., 2015. Screening field resistance to the root rot complex within the Andean Diversity Panel (ADP). Presentation at the Common Bean Disease Workshop on Angular Leaf Spot and Root Rot held in Skukuza, South Africa from 20 to 23 July 2015.

Viteri, D. M., H. Terán, M. C. Asensio-S.-Manzanera, C. Asensio, T. G. Porch, P. N. Miklas, and S. P. Singh. 2014. Progress in breeding Andean common bean for resistance to common bacterial blight. Crop Sci. 54: 2084-2092.

Professional Recognition

Dr. Juan Carlos Rosas received the 2014 Gamma Sigma Delta Distinguished Achievement in Agriculture Award.

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

Consuelo Estevez de Jensen, received an USDA/ARS Certificate of Appreciation for outstanding efforts to characterization of bean germplasm for enhanced BNF and root rot response for Feed the Future countries in support of the Feed the Future Grain Legumes Project, South Africa, July 1 2015.

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

XII. Data Management

A data management plan was submitted to the Legume Innovation Laboratory Management Office in July 2015. A scientist interested in using a data set generated with support from the

Legume Innovation Lab should contact the PI or Co-PI responsible for generating the data set to confirm how and for what purpose the data was collected. The PI or Co-PI responsible for maintaining the data set will follow the IPR policies of their institution.

ANNEXES

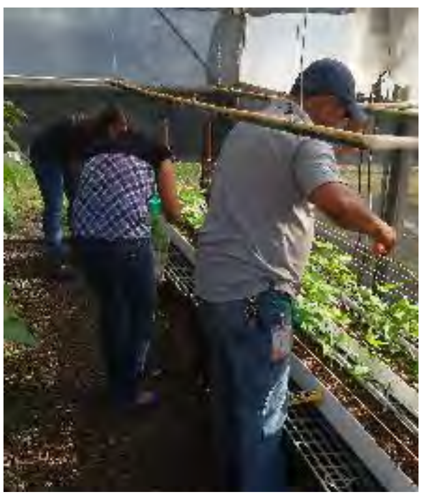
Annex 1. Tables, Figures, and Photos Cited in the Report

See below

Annex 2. Literature Cited

None

PVC gutter with sterilized gravel system (below left) for testing early nodulation in beans at Zamorano.



A soil:sand system (low in total N) for evaluating nodulation and BNF at Zamorano (above right). At the center, a row of plants from a nod nod line; the other rows are from lines selected for superior nodulation under a recurrent selection program.

Nodulation on a line selected at Zamorano for enhanced biological nitrogen fixation (BNF). The image on the right shows a chlorotic no-nod bean line bordered by lines selected for enhanced BNF