Feed the Future Innovation Lab for Collaborative Research on Grain Legumes
LEGUME INNOVATION LAB

2017 ANNUAL TECHNICAL PROGRESS REPORT
(October 1, 2016 – September 30, 2017)

Project Code and Title: S01.A3 Improving Genetic Yield Potential of Andean Beans with Increased Resistances to Drought and Major Foliar Diseases and Enhanced Biological Nitrogen Fixation (BNF)

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I. Abstract of Research and Capacity Strengthening Achievements

Common bean (*Phaseolus vulgaris*) is the most important grain legume consumed in Uganda and Zambia. The project has successfully identified local lines that are quicker cooking and these are being tested in on-farm trials with local producers in Uganda. Breeding programs in both countries continue to identify sources of disease resistance to many of the more serious pathogens that attack beans and are using these lines as parental material to further improve local varieties. Changes in climate are leading to less predictable rainfall patterns and the project has identified Andean breeding lines that perform better than local varieties under these conditions. Novel methodologies are being developed to screen more efficiently for cooking time and modern molecular tools have been deployed to map genomic regions that control anthracnose resistance. Genomic mapping with SNP markers and RNA sequencing has been used to pinpoint genomic regions that control anthracnose resistance, and enhanced symbiotic nitrogen fixation and candidate genes underlying these basis functions have been identified. The potential to enhance N-fixation in beans grown under low fertility conditions typical of subsistence farmers is now within the reach of local breeders. Training of future bean researchers continues to be a major objective by providing the environment to develop both scientific and leadership skills.

II. Project Problem Statement and Justification

Beans are the second most important food legume crop after ground nuts in Zambia and are a major source of income and cheap protein for many Zambians. Most of the bean crop (62%) is produced on 60,000 ha in the higher altitudes, cooler and high rainfall zones of the northern part of Zambia. Andean beans are predominant and land races are the most widely grown although a few improved cultivars are also grown as sole crops or in association mainly with maize. Bean production is constrained by several abiotic and biotic stresses that include diseases, pests, low soil fertility and drought. All the popular local landraces in Zambia are highly susceptible to pests and diseases that severely limit their productivity. This is reflected in the very low national yields ranging from 300 to 500 kg/ha that result in annual deficit of 5,000MT. To avert future food shortages and feed the growing population of 13M, there is critical need for increasing the productivity of most food crops including beans as Zambia ranks 164 out of 184 countries in the Human Poverty Index. Beans are an important crop in Uganda and are grown on over 660,000 ha of land and consumed throughout the country. Beans are a major source of food and income for the rural smallholder farmers especially the women and children. The majority of bean production in Uganda is dependent mainly on the use of inferior landrace varieties which are generally low yielding due to susceptibility to the major biotic and abiotic (drought, low soil fertility) stresses. These stresses gravely undermine the potential of the bean as a food security crop, a source of income, and as a main source of dietary protein for the majority of Ugandans. Drought affects 60% of global bean production and the severity of yield reduction depends on the timing, extent, and duration of the drought stress. The development of improved varieties and germplasm with high yield potential, healthy root systems, improved SNF with resistance to multiple diseases, and sustained or improved water use efficiency under limited soil water conditions are needed to increase profit margins, lower production costs. The project will use QTL analysis and SNP-based genome-wide association mapping to uncover regions associated with drought tolerance, disease resistance, enhanced BNF and faster cooking time.

III. Technical Research Progress

Objective 1: Integrate traditional and marker-assisted selection (MAS) approaches to combine resistances to economically important foliar diseases, drought and improved symbiotic nitrogen fixation (SNF) and assess acceptability of fast cooking, high mineral content in a range of large-seeded, high-yielding red mottled, white and yellow Andean bean germplasm for the Eastern Africa highlands (Zambia and Uganda), and the U.S.

1.1 Screen the disease nursery to different pathogens (ANT, and ALS field conditions in Uganda: Because of the complexities involves in the screening for resistance to anthracnose (ANT) and angular leaf spot (ALS), and the continued presence of these two diseases in the field throughout the year, it was deemed fit to undertake field screening of available nurseries. From the field screening local germplasm such as NABE 4, NABE 2, K131, and imported germplasm including Mexico 54, BAT 332 and PAN 72 were observed to be tolerant to ALS and the differential lines PI207262, TU, AB136 and G2333 did not show any anthracnose symptoms when screened at NaCRRI-Namulonge fields.

1.2 Complete screening for rust and CBB in Uganda: For rust, twenty-three single pustule rust isolates were collected in Uganda and inoculated on 11 rust differential bean lines and Ouro Negro (Ur-14). Six (6) rust pathotypes were identified with binary races 2-0, 4-0, 50-0, 5-1, 4-33 and 63-19. Five of the pathotypes were of Andean origin and only pathotype 4-33 was of Mesoamerican origin. The rust pathotype 63-19 showed similar pathogenic characteristics with the Puerto Rico rust race 63-19. From the screening of different germplasm, we identified seven (7) resistant lines that could be useful sources of resistance for breeding for bean rust resistance in Uganda and these included Mexico 309, CNC, P1181996, Mexico 235, Redland Pioneer, Ouro Negro and Aurora. Within the Uganda germplasm, fifteen (15) genotypes which included the landraces Nabufumbo, and Kapchorwa white, and the commercial genotype NABE2 were identified as new sources of rust resistance that would also be useful in future bean breeding efforts in Uganda. In the case of bean common bacterial blight (CBB), we used one virulent pathotype "Kawempe 1" and identified four (4) resistant bean lines with both leaf and pod resistance namely; NE2-14-8, NE17-14-29, NE14-09-78 and VAX3. In addition, we determined the mode of inheritance of CBB resistance for leaf and pod among selected Ugandan Andean genotypes. All these lines have been crossed with bean lines representing different Uganda market classes and progenies are undergoing evaluation.

1.3.1 Complete screening of the drought nursery in Uganda to intermittent drought stress: Using a drought nursery from the University of Nebraska-Lincoln comprising of 60 entries and the terminal drought screening protocol, we were able to identify seven (7) bean lines that showed drought tolerance tendencies and these include, ADP-102, ADP-41, ADP-47, ADP-61, ADP-617, ADP-660 and ADP-678. These will next undergo advance yield trial evaluation in different drought prone areas within the country. In addition, a set of eight (8) genotypes have gone through a series of multilocation evaluation trials across different agro-ecologies within Uganda. These genotypes were also made available to farmers through on-farm farmer participatory variety trials and were able to identify agronomically superior genotypes. From the evaluations, four (4) multiple disease and drought tolerant lines including SCR 26, SEN 98, SCN 11 and SCN 1 were identified as promising and have been sent for DUS/National Performance Trials (NPT). These are currently considered as candidate varieties for official release and one or two could possibly be released later in 2017.

1.3.2 Evaluation of Andean Diversity Panel (ADP) for drought stress response in Uganda.

A total of 256 ADP lines were evaluated in Uganda to assess their response to drought stress. The experiments were conducted at Mubuku Irrigation Scheme in Kasese a drought testing site in Uganda. This location on the leeward side of mountain Ruwenzori does not normally receive a lot of rain and has an irrigation facility making it a perfect site for conducting drought experiments. The second site was NaCRRI-Namulonge. The first drought experiments were conducted from November 2016 to February 2017 and included 247 ADP lines and 9 local checks. These genotypes were planted at Mubuku and NaCRRI-Namulonge under irrigated and non-irrigated conditions. However, we experienced bean fly infestation immediately after germination and this led poor plant stand. We decided to replant the drought experiment in Kasese and all experiments in Namulonge. Additional seed of the ADP lines from CIAT-Uganda was planted during the second season evaluation season from Mary 2017 to September 2017. The experiments were planted during off-season deliberately to synchronize drought stress with the reproductive stage. Drought stress was applied after flowering and water supplied to the Irrigated treatment until harvest. Data was collected on phenology traits, seed yield and yield component traits at harvest. Photosynthetic traits were measured during the pod filling stage using the PhotosynQ tool to determine the effects of reduced moisture on Photosynthetic traits. Significant variation was observed among the ADP evaluated for yield component traits and photosynthetic traits at reproductive stage. As expected, we observed highly significant and positive correlations among yield component traits, harvest index, pod harvest index and pod partition index with yield component trait. However, there were no significant correlations between yield component traits and photosynthetic traits measured using the photosynQ under rainfed conditions. Genomic regions associated with drought responses were determined using GWAS analysis and we detected significant signals for yield component traits and photosynthetic traits on Chromosomes Pv01, Pv4, Pv05, Pv06, Pv9, Pv10, and Pv11. Colocalized genomic regions were observed for yield component traits on Pv06 and for photosynthetic traits on Pv04 and Pv011. The candidate genes and their functional annotation are being explored. Using marker trait association effects, we identified accessions that carried alleles with high positive allele effects for pod weight per plant and seed weight per plant. Some of the accessions had previously been reported to have drought and heat tolerance. These genotypes are of diverse origin and market classes and could be used to improve the locally adapted germplasm for drought tolerance. In addition, 300 ADP lines were screened in the greenhouse at Namulonge to determine their response to drought stress at seedling stage. These genotypes were planted in plastic pots and watered for 21 days and withdrawn afterwards for 7 days. Data was collected on shoot traits by visual scores and Photosynthetic traits using the PhotosynQ tool during this time period. Water was then applied to check the recovery of genotypes after stress. The results of this data are being analyzed to determine the use of visual scores and photosynthetic traits to identify drought tolerant lines at seedling stage.

1.3.3 Identification of Quantitative Trait Loci (QTL) associated with drought tolerance in Portillo/Red Hawk recombinant inbred line (RIL) population: The second component of this study involved QTL mapping using Portillo/Red Hawk bi prenatal mapping population. The initially population size consisted of 113 individuals but we only evaluated 100 due to limited seed. The RIL population was evaluated in Uganda at the same locations, seasons, and conditions like the ADP. At the Mubuku Irrigation Scheme in Kasese, the RILs were evaluated for two seasons of 2016 and 2017 respectively. Meanwhile field evaluation in Namulonge was conducted in 2017 season. Preliminary results. We identified RILs that have exhibited high yield potential under drought condition and also have the preferred market class of Uganda, these lines will be further tested for other agronomic traits and eventually recommend for release. We identified a number of QTLs for yield component traits in a number of linkage groups. These results of all three studies will form part of Isaac Dramadri PhD dissertation at Michigan State University.

1.4 Evaluate populations generated from crosses between resistance sources for angular leaf spot (ALS), rust, anthracnose, common bacterial blight, virus resistance and drought tolerance with large seeded lines with contrasting colors in Uganda: The PIC lines are Andean RILs (The PIC lines are Andean lines for drought and heat tolerance that were generated by the Dr. Diedre Fourie's bean breeding program (ARC-Grain Crop Institute, Potchefstroom) that are drought tolerant genotypes that were obtained from southern Africa. In previous trials, we made single plant selections that were followed by single row family selections. In 2017A season, preliminary yield trails were conducted. Unfortunately, they were also severely hit by drought and some of the families were lost, so out of the 416 families that were established for yield trial evaluations, only 122 have been selected. Selection was based on lines that have desirable market class traits and ability to yield over 100 kg/ha considering the drought that occurred. Sixty-nine segregant populations within different market classes (Calima, yellows, and cranberries) combining sources of multiple disease resistance and slow cooking time were advanced to $F_{2:4}$ by bulking one pod per plant and are being distributed to Uganda and Zambia for individual plant selections in each country.

1.5 Cross lines with superior disease resistance to those with shorter cooking time and high mineral bioavailability. Crosses with CBB resistant and anthracnose resistant varieties from ADP and other sources: Resistance and tolerant genotypes obtained from different screening studies for rust, ALS, anthracnose, Sclerotium, CBB, BCMV, drought and fast cooking were crossed with different Uganda genotypes including K132, NABE 15, NABE 16, NABE 17, NABE 18, NABE 19 and

NABE 21, Masindi yellow, and KATB1. We were able to generate 356 different crosses and progenies arising from these crosses are at different stages of evaluation.

1.6 Advance crosses for anthracnose, bruchid and virus resistance in Uganda: Different resistances were introgressed into susceptible Uganda market class bean varieties, using identified sources of resistance. The progenies are being advanced and to date 144 promising lines have been selected to date.

1.7 Evaluation of National Nursery in Zambia

A number of both regional and national nurseries were evaluated for ANT, ALS, and CBB resistance to the three major diseases and these lines were advanced to multi-location trials while some were advanced to on farm evaluation under farmer conditions in Zambia. During the current year, the critical diseases observed on both climbers and bush types were anthracnose and common bacterial blight. A nursery of climbers from Rwanda was also evaluated for adaptation and yield. A number of lines were found to be adapted to Zambian conditions and will be further evaluated in multilocational trials, while four exceptional lines will proceed into on-farm evaluation trials. A high level of floury leaf spot was observed on these climbers. Enhanced resilience to drought was observed in the Mesoamerican gene pool, but with the challenge of climate change, it is hoped that these small seeded types will find a niche in the farming communities as they show resilient to drought. The program has advanced four small seeded lines for on-farm evaluation. The ADP was planted in two field experiments under rain-fed and irrigated conditions in Zambia in 2017. During the rainy season, there was a high incidence of CBB and ALS. This high incidence was useful for the identification of genotypes with resistance to CBB and ALS in Zambia. Identified genotypes with resistance to these two diseases, and higher productivity where crossed with Kabulangeti and Lusaka landraces, two popular landraces in Zambia. This is aimed at developing 'kabulangeti' and 'yellow' seed types that are resistant to CBB and ALS, in addition to being higher yielding. A total of six populations each with at least 400 F3 progenies were developed from these crosses, and will be planted in the field in 2018 for selections and population advancement at UNZA Research Farm and Misanfu Research Station in Lusaka and Kasama, respectively. Genome-wide association analysis was conducted using CBB data collected from the rain-fed field experiment to identify the genetic basis of the observed CBB resistance. From this analysis, genomic regions associated with CBB resistance have been identified. Samples of leaf tissue that showed symptoms of CBB were collected for culturing and isolation of the strain in the bean Breeding and Genetics Lab at University of Zambia. The isolated strain was inoculated on the ADP planted in the sreenhouse to avoid the confounding effect of phenology on CBB evaluations under field conditions. The assay is being fine-tuned and further evaluations in the screenhouse will be conducted in 2018.

1.8 Development of Kabulangeti' and Yellow seed type varieties

To develop 'kabulangeti' and 'yellow' seed type varieties for Zambia, Kabulangeti and Lusaka landraces were crossed with Uyole98, which is resistant to many races of anthracnose. Uyole98 is also resistant to ALS and Fusarium root rot. Two populations of 350 and 285 F3 progenies for Kabulangeti/Uyole98 and Lusaka/Uyole98 crosses, respectively, have been developed, and will be planted in the field in 2018 for selections and population advancement at UNZA Research Farm and Misanfu Research Station in Lusaka and Kasama, respectively. A sample of pods from the 2017 growing season that showed symptoms of anthracnose were sent to Michigan State University for isolation and race characterization. Anthracnose race 19 was identified as the causal race. Crosses of Kabulangeti and Lusaka with resistant genotypes that carry Co-4^2 resistance locus have since been made. Backcrosses of these crosses have been made, and marker-assisted selection for Co-4^2 locus is currently underway at the Bean Breeding and Genetics Lab at UNZA. Seeds of the 24 race differentials for ANT and ALS were requested from the CIAT gene bank in Colombia. The seed of these differentials was increased in the screenhouse at UNZA for the race characterization of the anthracnose and ALS pathogens in Zambia. A humidifier has been sourced from Michigan State University to help set-up the inoculation chamber at UNZA for anthracnose and ALS pathogens screening and race characterization.

1.9 Breeding for Drought Tolerance

The ADP was planted under irrigation in May 2017. A total of 275 ADP genotypes were planted in two replications under moisture stress and a control experiment of 275 ADP genotypes with two replications under no-moisture stress. These experiments were aimed at identifying Andean genotypes with tolerance to moisture stress. Identified genotypes with moisture stress were crossed with Kabulangeti and Lusaka landraces. Four populations of F2's with at least 300 genotypes for each population have been developed, and these will be planted in the field in 2018 for selections and population advancement at UNZA Research Farm and Misanfu Research Station in Lusaka and Kasama, respectively.

1.10 Breeding for Enhanced Biological Nitrogen Fixation

A population of F4:6 RILs derived from a cross of Solwezi and AO-1129-3-3A was planted at the UNZA Field station in January 2017 for evaluation for biological nitrogen fixation (BNF). Earlier, this population was evaluated for BNF in the greenhouse in two experiments in 2015 at Michigan State University. A total of 488 samples of leaf and seed tissue were collected from the field experiment at UNZA. These 488 samples were ground and shipped to University of California, Davis where they are currently being analyzed for N15 and nitrogen content. Results of this analysis will be used to map QTL for enhanced BNF under local field conditions in Zambia. Two Andean genotypes, Majesty and Inferno that were identified as high biological nitrogen fixers in earlier studies on this project, have been crossed with Kabulangeti and Lusaka landraces. These crosses are aimed at improving the nitrogen fixation abilities of the 'kabulangeti' and 'yellow' seed types that are popular in Zambia. Four populations of F3 have developed from these crosses and will be planted in the field in 2018 for selections and population advancement at UNZA Research Farm and Misanfu Research Station in Lusaka and Kasama, respectively.

1.11 Breeding for Resistance to the Common Bean Weevil

The Solwezi/A0-1129-3-3A population was also sent to University of Puerto Rico where it was evaluated for resistance to the common bean weevil, *Acanthoscelides obtectus*. Results of this evaluation have been used to identify novel QTL for resistance to the common bean weevil. Results of this evaluation showed that the common bean weevil resistance in the resistant parent could be transferred stably into other market classes. AO-1129-3-3A has since been crossed with Kabulangeti and Lusaka landraces, which are highly susceptible to common bean weevil infestation. Additionally, crosses of Kabulangeti and Lusaka, with AO-1129-3-1A and AO-1120-3-6B the other common bean weevil varieties developed at University of Puerto Rico were made in 2017. A total of six $F_{2:3}$ populations each with at least 300 genotypes have been developed from these crosses and will be planted in the field in the 2018 season. These populations are also being evaluated by a master's student at UNZA for resistance to bruchid biotype prevalent in Zambia.

1.12.1 Evaluation of Cooking Time

The cooking time of dry beans varies widely by genotype and is also influenced by the growing environment, storage conditions, and cooking method. Since this trait is experienced by consumers, influenced by many factors, and dynamic post-harvest, high throughput phenotyping methods to assess cooking time would be useful to breeders interested in developing cultivars with standardized cooking time and for food processors looking to optimize operations. The objective of this study was to evaluate the performance accuracy of a hyperspectral imaging (HYPERS) technology for predicting dry bean cooking time. Fourteen dry bean genotypes from five market classes and with a wide range of cooking times were grown in five environments over two years. Cooking time was measured as the number of minutes required for 80% of 25 stainless steel piercing rods to pass through a pre-soaked or unsoaked bean seed. Dry whole seed was hyperspectral imaged and the measurements were used to predict 1) water uptake, 2) cooking time of soaked beans, and 3) cooking time of unsoaked beans. Based on partial least squares regression models, water uptake predictions showed high sustained performance as expressed by their correlation coefficients for prediction (= 0.789) and standard error of prediction (= 4.4%). The measured cooking times for soaked beans ranged from 20 – 160 min. Cooking time predictions for soaked beans also showed sustained performance   = 0.886,   = 7.9 min. Cooking times were longer for unsoaked beans (ranging from 80 – 396 min) and their prediction models were less robust and accurate (r = 0.708, r = 10.6 min) (Annex 2, Table 1). The results of this study demonstrate that hyperspectral imaging technology has great potential for estimating water uptake and cooking time of dry beans in a nondestructive, simple, fast and economical way. Due to the genotypic and phenotypic variability of water absorption and cooking time in the dry bean, periodical updates of these sensing models with more samples and testing new bean accessions, as well as testing other multivariate prediction methods are further needed for improving model robustness and generalization performance.

1.12.1:

In 2017, dry beans selected for root rot resistance in Zambia were grown under terminal drought and normal conditions in Mitchell, NE. We explored the effect of drought on cooking time and water absorption for those sources. In general, dry beans under drought stress took 7 minutes longer to cook than under normal conditions. G10994, Larga Commercial, USDK-4, NE34-12-50, W16560, INIAP 414, and PI321094-D had the lowest root rot incidence. G10994 and INIAP 414 had the highest and lowest Geometric Mean, respectively. NE34-12-47 and NE34-12-50 had the lowest cooking time under DS and NS environments. G10994, Larga Commercial, W16560, INIAP 414, PI321094-D, NE34-12-28, and NE34-12-45 had the longest cooking time under both drought stress and normal conditions. These parents are being introgressed into elite Zambian germplasm. Under both drought stress and normal conditions, seed water absorption was negatively correlated with cooking time (r=-0.91** and -0.88**, respectively).

1.13 On farm evaluation for nutritional content

Common bean is an important source of protein and micronutrients and a target for iron biofortification programs. Biofortification has potential to address micronutrient malnutrition especially when plant based staples are widely grown and consumed. However, the efficacy of biofortified crops to address human malnutrition can further be improved by understanding the genotype x environment interaction for seed mineral concentration and ensuring high mineral bioavailability. Common bean genotypes with high iron and zinc concentrations, high iron bioavailability and fast cooking time phenotypes were identified through screening the Andean Diversity Panel. A subset of 15 nutritionally superior genotypes were identified and evaluated in farmers' fields along with local check genotypes in a participatory variety selection for two field seasons. Nine farmer groups each comprised of about 30 farmers participated in the field research. The growers were from districts representing three agro-ecological zones in Uganda that are important for dry bean production and consumption. A majority of the farmers preferred genotypes with upright architecture, many and longer pods, had red mottled or yellow grain color, and were high yielding especially under hostile growth conditions of too little or too much water. Seed yield across locations over the two growing seasons ranged from 400 to 2,050 kg/ha. ADP0445 from Puerto Rico was the most productive across locations and seasons. For the post-harvest preference scores 80% of the farmers selected genotypes ADP0001 and ADP0445 (red mottled), and ADP0468 and ADP0512 (yellows) as the most desired accessions. Cooking time was relatively stable across locations and yellow colored genotypes ADP0521 and ADP0512 generally cooked fastest. Based on the data from field trials, bean genotypes nutritionally superior to local checks and exhibiting good adaptation to the Ugandan bean production conditions were identified.

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

2.1 Increase seed of the differentials for ANT, ALS and rust in Zambia and Uganda: To acquire enough seed and for maintenance purposes, seed for the all the different differential was multiplied for both 2016B and 2017A seasons. Currently we have on average 0.6kg seed for the surviving differential. These will be used to characterize the different anthracnose, rust and angular leaf spot disease isolates that were obtained. The twelve rust differential lines were increased in Mitchell, NE in 2017. Seed is being shipped to Uganda and Zambia for the 2017B growing season.

2.2 Complete with race characterization for ANT, ALS and Rust in Uganda: Characterization of Rust, CBB, and BCMV were complete and reports have been included in thesis for Nwokocha Blessing Adanta Odogwu (2017), Alladassi Mahulé Elysé Boris (2016), and Evarist Basil Kavishe (2017) respectively. As for anthracnose, we managed to collect 51 isolates from eight districts and these were characterized into 27 different anthracnose pathotypes. A major concern is that 9/27 pathotypes attached all twelve differentials including the highly resistant genotype, G2333. 45 different isolates of ALS have had been obtained and these are currently being characterized.

2.3 Utilize the mobile nursery protocol to determine the effectiveness of rust resistance genes in genotypes in Zambia and Uganda: The use of the mobile nursery did not work out as anticipated. We instead used the improvised humid chambers artificially set up in the screen house using cheese cloth (Fig. 2). It is here that we introduced 2-litre disposable cups containing 10-days old bean plants that had been inoculated with spores of each isolates and were kept in a humid chamber at 18-23°C and 95% relative humidity for 16 hours. The plants were then air-dried before they were transferred into the open screenhouse. The plants were observed daily for pustule sporulation and rust development until they are 15 days old. The plants were then assessed for susceptibility status. This technique was the one used to determine the pathotypes.

2.4 The project will actively collaborate with MSU and UNL NIFA projects in Zambia and Uganda and with the S01.A4 project to address issues with a variety of pathogens (that are not being directly addressed in current workplan): Through collaboration with the NIFA project, more than 500 isolates of *Sclerotium rolfsii, Pythium spp., Fusarium spp. and Rhizoctonia spp* were isolated and preserved. From these 218 isolates of *S. rolfsii* were characterized using growth rates, colony type and number of sclerotia and from these Distinct differences were observed in virulence between isolates, where isolates Sir 400, Kap 417 and Hoi 344-2 (isolates from Sironko, Kapchorwa and Hoima, respectively), were found to be the most virulent. Using these isolates, we were able to identify four (4) sclerotium resistant bean lines (i.e. ALB 171, KWP 12, KWP 17 and KWP 9) and made crosses with five (5) Ugandan market class bean varieties including, K132, NABE 19, NABE 20, NABE 21 and NABE 22 and introgress sclerotium resistance into the background of these varieties. Progenies from these crosses are currently being evaluated.

2.5. *Anthracnose race characterization, screening in Zambia:* To understand the diversity of bean pathogens in Zambia, a survey was undertaken to collect seeds from farmers just before they planted there bean crop. This was to make sure the samples were collected from seed sources being planted. Three to four weeks after the farmers planted further collection of foliar samples were collected and these collections were used to isolate and characterized the bean pathogens. The disease symptom samples collected were those of ALS, ANT CBB and rust. These are being characterized by a ZARI pathologist under the supervision of Dr. K. Kamfwa in Lusaka.

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

3.1 Develop tightly linked SNP markers for major resistance genes: To enable the identification of single nucleotide polymorphism (SNP) markers associated with rust resistance and development of markers, we conducted GWAS with a total of 76,952 SNPs on 739 individuals from nine F3 population which were screened initially with rust pathotype 63-19. The study generated fifteen (15) SNPs associated with rust resistance and of these 10 genes were annotated namely, Phvul.002G008400, Phvul.002G010100, Phvul.002G010100, Phvul.002G011500, Phvul.003G187200, Phvul.003G294300, Phvul.005G018800, Phvul.005G058200, Phvul.005G114400 and Phvul.009G034600. These enabled us design eight (8) Kompetitive allele specific PCR (KASP) markers which will need to be validated for future MAS for rust resistance in Uganda.

3.2 Fast cooking lines with high mineral bioavailablity will be grown in on farm trials and will be evaluated for farmer acceptability based on agronomic and cooking characteristics: 23 ADP lines that were evaluated for shorter cooking time, adaptability, and consumer and market preference by nine (9) farmer groups composed of 326 farmers (96 men and 230 women) in three Ugandan agroecologies. By the end of the project, seven (7) lines namely ADP 0512, ADP 0009, ADP 0001, ADP 0468, ADP 0521, ADP 0098, and ADP 0522 had been selected by farmers through PVS trial as most preferred. These lines will be advance for further evaluation and will also be crossed with other Andean Uganda market class varieties and some will be advanced through national performance trails for possible releases in the future.

3.3 Conduct sensory evaluation of lines with superior cooking time and mineral bioavailablity in Michigan, Uganda, and Zambia: In Uganda, sensory evaluations for 15 nutritionally superior genotypes with close to 100 farmers/ consumers from the three districts of Hoima, Kamuli, and Masaka/Rakai getting involved in the post-harvest preference and preparation and sensory tasting (Fig. 4). From the results four (4) genotypes namely ADP0001 (Rozi Koko) and Chijar (both red mottled), and ADP0468 (PI527538) and ADP0512 (Ervilha) (both yellows) were most preffered, while two genotypes ADP0521 (Cebo, Cela) and ADP0512 (Ervilha) that cooked faster than other lines were most preferred based on taste.

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

Much of the research focused on examining constitutive differences between drought tolerant and drought susceptible genotypes so that mechanisms contributing to drought tolerance might be discovered and further investigated. To support these efforts, research was conducted on the physiology of drought and heat stress in a selection of bean genotypes with varying degrees of stress tolerance including tepary bean. Heat stress negatively impacts the yield of common beans and prevents their cultivation in certain areas. Furthermore, under field conditions, heat stress often coincides with and exacerbates the effects of drought stress. Breeding more heat tolerant common bean cultivars would stabilize yield and open new areas to production. To support these efforts, this research examined a variety of methods for screening large numbers of bean germplasm exposed to heat stress. Tepary bean (*P. acutifolius*), a closely related species, was used as a stress tolerant check. Bean plants exposed to temperatures of 45 °C for two days showed measurable signs of heat stress. Measures of gas exchange, chlorophyll fluorescence, and oxidative stress were for the most part only affected by this high temperature and not by any temperatures below 45 °C. These measures also correlated well with visual signs of damage on leaf tissue caused by heat stress. The method was useful for screening a large group of germplasm for heat tolerance, but this heat tolerance only partially related to drought tolerance observed in the field. Plant breeders can utilize some of the methods described here to supplement field data and further characterize the stress tolerance of later generation bean lines.

Objective 5:

Institutional Capacity Building and Training continues at MSU for two doctoral students, Isaac Dramadri, and Dennis Katuuramu from Uganda. Two doctoral students graduated in FY16, Kelvin Kamfwa from Zambia, and Jesse Traub, and one MS student Grady Zuiderveen student from the US all in Plant Breeding, Genetics and Biotechnology at MSU. Thesis title listed in Annex 1. In Uganda, three postgraduate students have been engaged and trained under the project. The students are at different levels of their research as indicated below;

Ms. Blessing Odogwu; was a Phd student at Makerere University undertaking studies under the research topic "Resistance to common bean (Phaseolus vulgaris L.) rust (Uromyces appendiculatus pers. [pers.]) Unger. in Uganda". Blessing completed her studies and submitted her PhD thesis. She is currently back home teaching at the University of Port Harcourt, Nigeria. She is waiting for her thesis defense.

Mr. Alladassi Mahulé Elysé Boris was an MSc. Student at Makerere University, Uganda, where he conducted research on the "Genetics of resistance to Common Bacterial Blight disease of

Common Bean (Phaseolus vulgaris L.) in Uganda”. Boris was able to graduate and he is currently teaching post-graduate students at Makerere University, Kampala, Uganda.

In addition to graduate student training, we were able to train eight (8) technicians, two (2) research assistants and 10 MSc students on the use of the photosynQ for field phenotyping. Mr. Basil Evarist Kavishe was also an MSc. Student at Makerere University, Uganda where he conducted research on the “Resistance to bean common mosaic potyviruses and its inheritance in selected Ugandan beans” Evarist completed his studies and submitted his thesis for examination. He is currently back home in Tanzania.

In Zambia, through the network of stakeholders in the bean value chain ZARI managed to train 757 (472 males and 285 females) small-scale farmers. The farmer trainings were conducted in eight districts of the three provinces where bean production is high. The farmers were trained in seed production principles, crop protection, post-harvest handling and integrated crop management. These efforts are meant to improve the availability of high quality improved bean seed in the communities.

IV. Major Achievements

The project has continued to make significant achievement towards achieving the breeding objectives especially in the area of germplasm acquisition and utilization. We have also continued with having working relationships between NaCRRI and other institutes like Makerere University, Michigan State University, University of Nebraska and in country USAID Field Mission. We have also continued our engagements with postgraduate students, farmers, NGOs and Community Based Organization (CBOs) in bean growing agroecologies in Uganda. The research achievements so far obtained are inclusive but not limited to the following:

- Through the project we have continued to identify and utilize resistance for rust, CBB, BCMV, Sclerotium root rot and drought and made crosses to introgress these resistant genes into the susceptible Uganda Andean market class bean varieties. To date 356 crosses have been made and these are being evaluated at different filial stages.
- Have identified promising drought tolerant lines SCR 26, SEN 98, SCN 11 and SCN 1 and sent then for DUS/NPT trials, hoping for possible variety by end of 2017.
- Seven (7) lines with shorter cooking time namely ADP 0512, ADP 0009, ADP 0001, ADP 0468, ADP 0521, ADP 0098, and ADP 0522 have been selected by farmers through PVS trial as most preferred.
- Identified seven (7) resistant lines to rust including; Mexico 309, CNC, P1181996, Mexico 235, Redland pioneer, Ouro Negro and Aurora.
- Determined the mode of inheritance of rust resistance for selected Ugandan Andean genotypes
- Identified resistant four (4) lines with both leaf and pod resistance for CBB including NE2-14-8, NE17-14-29, NE14-09-78 and VAX3.
- We determined the mode of inheritance of CBB resistance for leaf and pod among selected Ugandan Andean genotypes
- Identified three (3) resistant lines to BCMV including; SCR 48, SCN 9 and SCN 6.
- Determined the mode of inheritance of genes for BCMV and BCMNV resistance in Uganda Andean bean genotypes

- Identified four (4) lines with relatively good resistance to *Sclerotium rolfsii* root rot including; ALB 155, ALB 171, KWP 17 and KWP 9
- Identified 7 lines with tolerance to drought including; ADP-102, ADP-41, ADP-47, ADP-61, ADP-617, ADP-660 and ADP-678
- Designed eight (8) KASP markers associated with rust resistance that will need to be validated.
- Obtained on average about 0.6 kg of seed of each differential for rust anthracnose and ALS.
- Trained one (1) PhD and two (2) MSc. students
- We have built capacity for eight (8) technicians, two (2) research assistants and 10 MSc students on the use of the photosynQ for field phenotyping for drought.
- At least 5 NGOs were supported through training of their clients (farmers) and extension agencies
- 757 famers (472 male and 285 female) were trained in total during the period under review
- An increase in the quantity of foundation bean seed under the supervision of the bean team has been noted with 2016/17 season producing 21Mt in Zambia
- Characterization of Bean pathogens is underway and will be completed within the next 2 months
- Advancing of four drought resilient lines for On-farm evaluation in Zambia
- On-farm evaluation of climbers for adaptation to the small holder farming system
- A number of lines were found to be resistant to major bean diseases in the country
- Through this project high throughput non-destructive phenotyping tools for bean end use quality traits. Hyperspectral imaging models were developed that predict cooking time within 10 minutes of actual values (Mendoza et al., in preparation). Visible and near infrared reflectance spectroscopy (visible/NIRS, 400–2498 nm) of intact dry black beans predicted canned bean texture to R prediction values as high as 0.866 (Mendoza et al., 2017).
- Genotype by environment interaction for cooking time and seed iron and zinc concentrations were elucidated across nine on farm locations in Uganda. Wide genotypic variability for cooking time was observed (19 to 272 minutes). Two yellow beans (Cebo Cela and Elvhira) were consistently fast cooking (25 min avg.) across locations and years (Katuuramu et al., in preparation).

V. Research Capacity Strengthening

The collaborative research has enabled us to build research capacity at NaCRRI not only in terms of breeding activities but also in developing human resource capacity. In this year we were able to continue training and mentoring one PhD and two MSc students. We are also able to train a three research assistant and 5 technicians in Uganda on the use of modern technologies to capture field data and reduce on errors. Also the host country PI-Uganda, was facilitated to attend and participate in a common bean disease workshop on angular leaf spot and root rot where new insights and methods were shared on how to combat these two diseases. We also able to network with other renowned scientists and sharing research information and knowledge. For human capacity building, two short term trainings were organized for research assistants and technicians in Uganda. This was to strengthen their research capability in as far as data collection is concerned. There was training on the use of new data collection tools as part of breeding management system which tools are being utilized by the project.

We received research capacity strengthening funds to test a modified PhotosynQ for use in predicting cooking time. Unfortunately, the PhotosynQ did not work well for this purpose. All the measurements and the analysis were done in parallel with Vis/NIRS and hyperspectral, but the predictions for the hand held sensor were poor and sometimes unusual. This could be explained by the complexity of the phenomena to model in combination with the low range of spectral wavelengths (i.e., number of wavelengths) used for analysis.

VI. Human Resource and Institution Capacity Development

2. Degree Training

In the aspect of capacity building, three postgraduate students have been engaged and trained under the project. The students have all complete their studies in the areas indicated and at different levels towards graduation as indicated:

Mr. Isaac Dramadri is a PhD student at Michigan State University who is conducting his research work in Uganda on "Genomic and phenometric approaches to dissect physiological responses associated with drought adaptation within the Andean common bean genepool". Isaac his currently completing the writing up of his dissertation.

The PhD student (**Ms. Blessing Odogwu**), continued to undertake her research work on rust with the project. Through the Norman E. Borlaug Leadership Enhancement in Agriculture Program fellowship, she was also able to travel to MSU and University of Nebraska to undertake hands-on training of the use of molecular markers for screening purposes. In addition, two other MSc. students have been taken on by the project to undertake their researchers on under some of our project objectives. The first MSc. student is looking at breeding for resistance to CBB while the second student is conducting research on the BCMV disease. It hoped that the three students will make positive contribution towards new discoveries and also gain experience in research implementation. Details for the students are given below;

Student 1

i. Name of trainee: Blessing Odogwu
ii. Country of Citizenship: Nigeria
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: University of Port Harcourt, Nigeria
v. Institution providing training: Makerere University/NaCRRI
vi. Supervising CRSP PI: James Kelly
vii. Degree Program: PhD
viii. Field or Discipline: Plant Breeding and Biotechnology
ix. Research Project Title: Breeding for rust resistance in common beans in Uganda
x. Start Date: January 2014
xi. Projected Completion Date: December 2017
xii. Is trainee a USAID Participant Trainee and registered on TraiNet?: No
xiii. Training status: Active

Student 2

i. Name of trainee: Boris Mahulé Elysé Alladassi
ii. Country of Citizenship: Benin
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: University of Abomey-Calavi, Benin
v. Institution providing training: Makerere University/NaCRRI
vi. Supervising CRSP PI: None

vii. Degree Program: Masters Degree
viii. Field or Discipline: Plant breeding and seed systems
ix. Research Project Title: Genetic Analysis of Resistance to Common bacterial blight and association of candidate SNP markers of common bean (*Phaseolus vulgaris L.)* in Uganda
x. Start Date: December 2014
xi. Projected Completion Date: September 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet?: No
xiii. Training status: Active

Student 3

i. Name of trainee: Basil Evarist Kavishe
ii. Country of Citizenship: Tanzania
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: Sokoine University of Agriculture, Tanzania
v. Institution providing training: Makerere University/NaCRRI
vi. Supervising CRSP PI: None
vii. Degree Program: Masters Degree
viii. Field or Discipline: Plant breeding and seed systems
ix. Research Project Title: Resistance to bean common mosaic virus and its inheritance in selected Ugandan bean genotypes
x. Start Date: December 2014
xi. Projected Completion Date: September 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet?:No
xiii. Training status: Active

Student 4

i. Name of trainee (First and Last Name): Kelvin Kamfwa
ii. Citizenship: Zambian
iii. Gender: M
iv. Training Institution: MSU
v. Host Country Institution Benefitting from Training: University of Zambia
vi. Supervising Legume Innovation Lab PI: James D. Kelly and Karen A. Cichy
vii. Degree Program for training: Doctorate
viii. Program Areas or Discipline: Plant Breeding, Genetics and Biotechnology
ix. Thesis Title/ Research Area: Genetic dissection of biological nitrogen fixation in common bean using genome-wide association analysis and linkage mapping.
x. Start Date: August 2008
xi. Completion Date: December 2015
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
xiii. Training Status: graduated

Student 5:

i. Name of trainee (First and Last Name): Grady Zuiderveen
ii. Citizenship: US
iii. Gender: M
iv. Training Institution: MSU
v. Supervising Legume Innovation Lab PI: James D. Kelly

vi. Degree Program for training: Masters
vii. Program Areas or Discipline: Plant Breeding, Genetics and Biotechnology
viii. Host Country Institution to Benefit from Training: US
ix. Thesis Title/ Research Area: SNP marker development for major resistance genes
x. Start Date: August 2013
xi. Completion Date: September 2015
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training Status: graduated

Student 6:

i. Name of trainee (First and Last Name): Jesse Traub
ii. Citizenship: US
iii. Gender: M
iv. Host Country Institution to Benefit from Training: US
v. Training Institution: MSU
vi. Supervising Legume Innovation Lab PI: Wayne Loescher
vii. Degree Program for training: Doctorate
viii. Field or Discipline: Plant Breeding, Genetics and Biotechnology
ix. Thesis Title/ Research Area: Physiological differences among *Phaseolus vulgaris* cultivars differing in drought tolerance.
x. Start Date: August 2013 on Legume Innovation Funding
xi. Completion Date: January 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training Status: graduated.
xiv.

Student 7:

i. Name of trainee (First and Last Name): Isaac Dramadri
ii. Citizenship: Uganda
iii. Gender: M
iv. Host Country Institution to Benefit from Training: Makerere University
v. Training Institution: MSU
vi. Supervising Legume Innovation Lab PI: James D. Kelly and Wayne Loescher
vii. Degree Program for training: Doctorate
viii. Field or Discipline: Plant Breeding, Genetics and Biotechnology
ix. Thesis Title/ Research Area: Physiological studies on drought tolerance in Andean beans.
x. Start Date: August 2013 on Legume Innovation Funding
xi. Projected Completion Date: May 2018
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
xiii. Training Status: Active, Partial -BHEARD Fellowship from USAID Mission, Kampala.

Student 8:

xiv. Name of trainee (First and Last Name): Dennis Katuuramu.
xv. Citizenship: Uganda
xvi. Gender: M
xvii. Host Country Institution to Benefit from Training: National Crops Resources Research Institute
xviii. Training Institution: MSU
xix. Supervising Legume Innovation Lab PI: Karen Cichy
xx. Degree Program for training: Doctorate
xxi. Field or Discipline: Plant Breeding, Genetics and Biotechnology

xxii. Thesis Title/ Research Area: On farm GxE and farmer participatory evaluation of fast cooking and nutritious dry bean lines
xxiii. Start Date: August 2012
xxiv. Projected Completion Date: December 2017
xxv. Is trainee a USAID Participant Trainee and registered on TraiNet? NO
xxvi. Training Status: Active, Partial, USDA-ARS funding.

VII. Achievement of Gender Equity Goals

During the execution of the project, we did take a deliberate effort to ensure that both men and women are equitably considered in all project activities. This has been shown in all farmer activities, short and long-term training for technicians, research assistants and post graduate students. We have been able to achieve more than the 30 percent women representation that has been set during project planning. The farmer groups in Uganda involved in the participatory evaluation of beans were in most cases led by women. In addition, we focused on traits important to women including cooking time and nutritional density in this study.

VIII. Explanation for Changes

None.

IX. Self-Evaluation and Lessons-Learned

None

X. Scholarly Accomplishments – See Annex 1

XI. Progress in Implementing Impact Pathway Action Plan

The project is on track toward implementing the impact pathway. All activities listed under step 4.1 of the impact pathway have been met with the exception of disease characterization in country and those activities will be conducted during FY17. The achievements outlined above have encountered challenges mainly due to the severe drought that was experienced during the first season 2017, where we lost quite a significant number of experiments in Uganda. To solve the problem and save some of the seed, we invested in on-spot irrigation with improvised pumps and this save us some of our precious seed.

ANNEXES

Annex 1: Scholarly Accomplishments- Refereed Publications:

1. Ai, Y., Y. Jin, J. D. Kelly, and P. K.W. Ng. 2017. Composition, functional properties, starch digestibility, and cookie-baking performance of dry bean powders from 25 Michigan-grown varieties. Cereal Chemistry 94:400-408. doi: 10.1094/cchem-04-16-0089-r
2. Alladassi, B.M.E., S.T. Nkalubo, C. Mukankusi, E. S. Mwale, P. Gibson, R. Edema, C.A. Urrea, J. D. Kelly, and P. R. Rubaihayo. 2017. Inheritance of resistance to common bacterial blight in four selected common bean (*Phaseolus vulgaris* L.) genotypes. J. Plant Breed. Crop Sci. 9:71-78. doi: 10.5897/JPBCS2017.0644
3. Bruno, A. Mukankusi, M. C., Nkalubo, T. S., Gibson, P., Malinga, G. M., Rubaihayo, P., and Edema, R. 2017. Variety × environment × management interaction of diseases and yield in selected common bean varieties. Agron. J. 109:2450–2462.
4. Heilig, J.A. J. S. Beaver, E. M. Wright, Q. Song, and J. D. Kelly. 2017. QTL analysis of symbiotic nitrogen fixation in a black bean population. Crop Sci. 57: 118-129. doi:10.2135/cropsci2016.05.0348
5. Heilig, J.A., E.M. Wright, and J.D. Kelly. 2017. Symbiotic N fixation of black and navy beans under organic production systems. Agron. J.109:1-8. doi: 10.2134/agronj2017.01.0051
6. Kamfwa, K., D. Zhao, J. D. Kelly and K. A. Cichy. 2017. Transcriptome analysis of two recombinant inbred lines of common bean contrasting for symbiotic nitrogen fixation. PLoS ONE 12(2):e0172141. doi:10.1371/journal.pone.0172141
7. McClean, P.E., S.M. Moghaddam, A-F. Lopez-Millan, M. A. Brick, J. D. Kelly, P. N. Miklas, J. M. Osorno, T. G. Porch, C.A. Urrea, A. Soltani and M. A. Gruzak. 2017. Phenotypic diversity for seed element concentration in North American dry bean germplasm of Middle American Ancestry. Crop Sci. 57:3129-3144. doi:10.2135/cropsci2017.04.0244
8. Mendoza, F.A., K.A. Cichy, C. Sprague, A. Goffnett, R. Lu, and J.D. Kelly. 2017. Prediction of canned black bean texture (*Phaseolus vulgaris* L.) from intact dry seeds using visible/near-infrared spectroscopy and hyperspectral imaging data. J. Sci. Food Agric. doi: 10.1002/jsfa.8469
9. Mendoza, F. A., Kelly, J. D., and Cichy, K. A. 2017. Automated prediction of sensory scores for color and appearance in canned black beans (*Phaseolus vulgaris* L.) using machine vision. International Journal of Food Properties, 20(1), 83-99.
10. Odogwu, B.A., S. T. Nkalubo, C. Mukankusi, T. Odong, H. E. Awale, P. Rubaihayo, and J. D. Kelly. 2017. Phenotypic and genotypic screening for rust resistance in common bean germplasm in Uganda. Euphytica 213:49. doi: 10.1007/s10681-016-1795-y
11. Odogwu, B.A., Nkalubo, S., Mukankusi, C., McCoy, S., Paparu, P., Rubaihayo, P., Kelly, J.D. and Sadman J. 2016. Prevalence and variability of the common bean rust in Uganda. African Journal of Agricultural Research. 11(49), 4990- 4999. doi:10.5897 /ajar2016.11600 issn: 1991-637x.
12. Odogwu, B.A., Nkalubo, S. and Rubaihayo, P. 2016. Genetic analysis of resistance to common bean rust disease in Uganda. RUFORUM Working Document Series (ISSN 1607-9345) No. 14 (1): 699-705. http://repository.ruforum.org. 7x.
13. Padder, B.A., P.N. Sharma, H.E. Awale, and J.D. Kelly. 2017. *Colletotrichum lindemuthianum*, the causal agent of bean anthracnose. J. Plant Pathology 99: 317-330. doi: 10.4454/jpp.v99i2.3867
14. Rossman, D.R., A. Rojas, J.L. Jacobs, C. Mukankusi, J.D. Kelly, and M.I. Chilvers. 2017. Pathogenicity and virulence of soilborne oomycetes on dry bean (*Phaseolus vulgaris*). Plant Disease. doi.org/10.1094/PDIS-02-17-0178-RE

15. Traub, J., J. D. Kelly, and W. Loescher. 2017. Early metabolic and photosynthetic responses to drought stress in common and tepary bean. Crop Sci. 57:1-17. doi:10.2135/cropsci2016.09.0746

Journal article under review

1. Alladassi, B.M.E., S. T. Nkalubo, C. Mukankusi, H. N. Kayaga, P. Gibson, R. Edema, C. A. Urrea, J. D. Kelly and P. R. Rubaihayo. 2017. Screening of common bean germplasm for combined leaf and pod resistance to common bacterial blight disease in Uganda. Manuscript under review in Crop Breeding and Applied Biotechnology Journal.
2. Isaacs, K.B., S.S. Snapp, L. Butare, and J.D. Kelly. 2017. Genotype by cropping system interactions in climbing bean and maize associations in Northern Province, Rwanda. Field Crops Res. (submitted).
3. Kelly, J.D. 2017. Developing improved high-yielding varieties of common bean. Ch.18. In: Achieving sustainable cultivation of grain legumes (ed. Sivasankar et al) Burleigh Dodds Science Publishing (in press).
4. Kelly, J.D., G.V. Varner, P. N. Miklas, K. A. Cichy and E.M. Wright. 2017. Registration of 'Cayenne' small red bean. J. Plant Regist. (Review).
5. Kelly, J.D., G.V. Varner, M.I. Chilvers, K. A. Cichy and E.M. Wright. 2017. Registration of Red Cedar' dark red kidney bean. J. Plant Regist. (Review).
6. Mendoza, F.A., Wiesinger, J.A., Cichy, K.A., Lu, R. and Kelly, J.D. Prediction of cooking time for soaked and unsoaked dry beans (Phaseolus vulgaris L.) using hyperspectral imaging technology. In preparation for The Plant Phenome Journal.
7. Odogwu, B.A; Nkalubo, S.T; and Rubaihayo, P. (2017) Yield loss associated with common bean rust in Uganda. (2017). Manuscript under review in Field Crops Journal.
8. Odogwu, B.A.; Yao, N.; Odeny, D.; Shorinola, ONjung'e, Nkalubo, S.T. and Rubaihayo, P 2017. SNP identification and marker assay development for high-throughput selection of bean rust resistance. Manuscript under review in PLOS ONE Journal.
9. Traub, J., T. Porch, M. Naeem, G. Austic, J. D. Kelly, and W. Loescher. 2017. Screening for heat tolerance in *Phaseolus* spp. using multiple methods (preparation).
10. Wang, W., J.L. Jacobs, M.I. Chilvers, C. M. Mukankusi, J.D. Kelly, and K.A. Cichy. 2017. QTL analysis of Fusarium root rot resistance in an Andean x Middle American RIL population. (Submitted Crop Sci.).

<u>Presentations, Dissertations, Patents and Awards:</u>

Poster & paper presentations

1. Traub, J.R., J.D. Kelly, and W. Loescher. Physiological components of heat and drought tolerance differences in *Phaseolus vulgaris* and *P. acutifolius. Presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
2. Dramadri O.I., S.T. Nkalubo., and J. D. Kelly. Genome Wide Association Analysis for Terminal Drought Tolerance in Andean Common Beans. *Presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso*
3. Kamfwa K., D. TerAvest, J.D. Kelly, and D. Kramer. 2017. Harnessing PhotosynQ-connected Phenotyping Technologies for Common Bean Breeding in Zambia. *Presented*

during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.

4. Urrea, C.A., S. Nkalubo, K. Muimui, J.D. Kelly, J. Steadman, and E.V. Cruzado. Effect of drought on bean cooking time using germplasm selected for drought, common bacterial blight, and root rot resistance for Uganda and Zambia. *Presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
5. Nkalubo T. S., B.A.Odogwu, B.M.E. Alladassi, E. B. Kavishe, I. Dramadri, D. Katuramu, G. Luyima, K. Cichy, C. Urrea, J. Steadman and J.D. Kelly. Genetic Improvement in Uganda's Andean Bean Breeding Program. *Poster presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
6. Katuuramu D.N, J.D. Kelly, G.B. Luyima, S.T. Nkalubo, R.P. Glahn, and K.A. Cichy. Agronomic and Sensory Attributes Evaluation of Nutritionally Superior Common Bean (*Phaseolus vulgaris* L.) Genotypes with Farmers from Three Agro-ecological Zones in Uganda. *Poster presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
7. Muimui, K. K., A. L. Okello, P. Chikuma, R. Lungu. Enhancing bean productivity through community seed multiplication in Mbala and Mporokoso districts of Northern Zambia, Poster Presentation at the *Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*
8. Steadman, J., B. Odogwu, S. Nkalubo, C. Mukuma, K. Muimui, J. Millhouse, and C. Urrea. Search for resistance to bean rust in Zambia and Uganda: Field and greenhouse tools. *Poster presented during the Feed the Future Legume Innovation Lab Grain Legume Research Conference 13 to 18 August 2017, Ouagadougou, Burkina Faso.*

Non-refereed Publications:

1. Bornowski, N., F. A. Mendoza, and J. D. Kelly. 2017. Mapping and predicting color retention and other quality traits in black bean populations. Ann. Rep. Bean Improv. Coop. 60:151-152.
2. Vandemark, G.J., M. A. Brick, J. D. Kelly, J.M. Osorno, and C.A. Urrea. 2017. Yield gains in dry beans in the U.S. Ann. Rep. Bean Improv. Coop. 60: 183-184.
3. Steadman, J., and C.A. Urrea. 2017. Uganda trip report (Nov. 11-16, 2016). The Bean Bag. 35(1): 10 & 11.

Patents:

None

Awards:

James R. Steadman received the Meritorious Achievement Award presented by the Feed the Future Legume Innovation Lab at the Grain Legume Research Conference in Ouagadougou, Burkina Faso.

Kelvin Kamfwa received the Early Career Grain Legume Scientists Award in recognition of early career achievement in grain legume research and commitment to improving the livelihoods of smallholder farmers in developing countries. The award was presented by the Feed the Future Legume Innovation Lab at the Grain Legume Research Conference in Ouagadougou, Burkina Faso.

Thesis:

Ms. Blessing Odogw; was a Phd student at Makerere University who conducted her on bean rust disease. Blessing completed her research work and submitted her desertion entitled "Resistance to common bean (Phaseolus vulgaris L.) rust (*Uromyces appendiculatus* (Pers. Pers.) Unger.) in Uganda" for examination. She has returned to her home country Nigeria and is teaching at University of Port Harcourt, Nigeria.

Mr. Alladassi Mahulé Elysé Boris was an MSc. student at Makerere University, Uganda, and conducted research on CBB. Boris completed his research work and has already graduated. His research was entitled "Genetics of resistance to Common Bacterial Blight disease of Common Bean (*Phaseolus vulgaris* L.) in Uganda". Mr. Alladassi is currently teaching post graduate students at Makerere University.

Mr. Basil Evarist Kavishe was also an MSc. Student at Makerere University, Uganda who conducted research on the "Resistance to bean common mosaic potyviruses and its inheritance in selected Ugandan beans" Evarist has also submitted his dissertation and he is waiting for graduation.

Annex 2: TABLES

Table 1 Calibration and prediction results of cooking time [min] using hyperspectral imaging on a panel of intact dry beans for soaked and unsoaked seeds.

	UNSOAKED (From 80.1 to 147.0 min, 127 samples)					**SOAKED** (From 19.9 to 95.5 min, 122 samples)				
	Avg. Fact.	$\overline{R}_{cal}$	$\overline{SEC}$	$\overline{R}_{pred}$	$\overline{SEP}$	Avg. Fact.	$\overline{R}_{cal}$	$\overline{SEC}$	$\overline{R}_{pred}$	$\overline{SEP}$
Smooth	7	0.711	9.6	0.573	11.4 [A]	7	0.783	9.7	0.694	11.0 [E]
1Der	5	0.652	10.4	0.513	11.9 [B]	7	0.769	10.0	0.668	10.8 [C]
2Der	8	0.765	8.8	0.637	10.9 [C]	14	0.946	4.2	0.739	9.8 [F]
CWT	10	0.945	4.5	0.708	10.6 [D]	14	0.983	2.9	0.886	7.9 [G]

Smooth, 1Der, 2Der, CWT and Ratios: Smoothing, first derivative, second derivative, continues wavelet transform decomposition, respectively, combined with the two-band ratios preprocessing method.

Avg. Fact.: Average number of features required for the partial least square model after optimization

$\overline{R}_{cal}$ and $\overline{R}_{pred}$: Average correlation coefficients of calibration and prediction, respectively, over four calculations

$\overline{SEC}$ and $\overline{SEP}$: Average standard error for calibration and prediction, respectively, over four calculation

[A, B, C, D, E, F, G] Same letters in rows and columns represent no-significant differences (p-values ≥ 0.05).