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

FY 2016 Annual Project Technical Progress Report
(October 1, 2015 – September 30, 2016))

Project Code and Title:

SO1.A2 Improving Photosynthesis in Grain Legumes with New Plant Phenotyping Technologies

Lead U.S. Principal Investigator and University:

David M. Kramer Biochemistry and Molecular Biology and Plant Research Lab, Michigan State University

Collaborating Host Country and U.S. PIs and Institutions:

Kelvin Kamfwa, University of Zambia
Kennedy Muimui, ZARI, Zambia
Wayne Loescher, MSU
James Kelly, MSU
Tim Close, U.C. Riverside
Phil Roberts, U.C. Riverside
Maren Friesen, MSU, Plant Biology

I. Abstract of Research and Capacity Strengthening Achievements

(A succinct narrative on the technical progress of the project, including key research and capacity strengthening achievements and outcomes, during the FY 2016 performance and report period. 1200 character limit.)

In FY 2016 we made substantial progress on all our aims. A key component of this effort is the development, dissemination and application of phenotyping technologies with our partners to identify target processes and genes for improvement of photosynthetic responses in beans and cowpeas. There are two major components to the project: bringing the lab to the world, through an open access science platform we developed called PhotosynQ that brings cutting edge phenotyping and analytics technologies to field researchers around the world.

A publication describing the development, characterization and initial use of the MultispeQ has just been published. We delivered 6 MultispeQ beta devices to the

University of Zambia (UNZA), and are following up with a set of the newly-released version of the device. We also trained seven undergraduate students at UNZA, and two research technicians at Zambia Agricultural Research Institute (ZARI), who collected quality field measurements of common bean GWAS lines for QTL mapping. Based on initial results from our collaboration with UNZA we have revised the MultispeQ, developed new protocols and procedures to improve the statistical sampling of phenotype data and developed analytical methods to process complex interactions among photosynthetic and environmental parameters. In a major achievement, UNZA has produced a complete proof-of-concept GWAS mapping for photosynthetic responses of common beans to drought using the PhotosynQ platform.

II. Project Problem Statement and Justification

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

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

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

III. Technical Research Progress

(*Describe the research activities (research methods, studies conducted, analyses completed, and significant findings) completed under each objective during the FY 2016 reporting period. Present sufficient detail so that the reviewers will understand and have confidence that the research was carried out in a manner that meets high scientific standards. Briefly discuss primary results, findings, and/or technological achievements that give evidence of technical progress toward objectives. Please be reminded to highlight significant outputs that have potential for impact.*)

If certain research activities described in the FY 2016 Workplan were not completed, they must be identified and an acceptable explanation provided in the field ***(VIII) "Explanation for Changes."***

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

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

At MSU, we have successfully mapped key QTL's using controlled conditions at MSU using the DEPI chambers, and demonstrated the approach for distinguishing genetic variation in the responses of photosynthesis to both low and high temperatures. From these results, we have determined which conditions and MAGIC populations are best suited for QTL mapping for photosynthetic responses to temperature, and the experimental protocols are in the process of being performed and analyzed.

Objective 2. Increase the capacity, effectiveness and sustainability of agriculture research institutions which serve the bean and cowpea sectors in the target FTF countries by establishing an African-USA community of networked scientists, extension agents, students and growers to address field-level research and production questions.

In FY 2016 we made major strides towards achieving this objective. In December, 2015 Kelvin Kamfwa completed his doctorate training at MSU and moved to the University of Zambia. At the same time we distributed 6 MultispeQ instruments and 6 android mobile devices to the University of Zambia. Dr. Kamfwa trained six undergraduate students on the MultispeQ and the PhotosynQ platform, and students began collecting PhotosynQ data. Furthermore, in March 2016 David Kramer and Dan TerAvest visited UNZA and trained undergraduates on data collection methodologies and the plant physiological parameters measured by the MultispeQ instrument. The result of these combined trainings are that students at UNZA have collected over 4,000 MultispeQ measurements on the common bean Andean Diversity Panel.

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

Objective 3. Development of Data Management Plan

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

IV. Major Achievements

(*Present a **list of significant research achievements and/or technical advances resulting from project activities during the FY 2016 performance period**. The description of each achievement need not be more than three sentences long. Quantitative information on or a technical description of the research achievement would be appreciated because it adds credibility to the importance of the achievement*.)

1. Dissemination and publication of the PhotosynQ beta instrument (Kuhlgert et al., 2016)
2. Development of the Version 1.0 device
3. First proofs-of-concept for the complete QTL mapping process for photosynthetic properties in common beans using PhotosynQ at the University of Zambia.
4. Training of several graduate students at both UNZA and MSU.
5. Development of a new PhotosynQ-guided experimental protocols.

V. Research Capacity Strengthening

(*Describe how collaborative research activities supported by the project during FY 2016 have contributed to the strengthening of institutional capacity to carry out multidisciplinary research on grain legumes and to solve the problems facing the legume sectors in host countries and regions. Appropriate capacity strengthening items to present in this section include research equipment procured (>$5,000), laboratory and analytical facilities developed, participation in professional meetings or other networking activities, etc. Please also identify in this section the activities completed and equipment procured with supplemental Institutional Capacity Strengthening funds received by host country institutions in the respective project.)*

We have made progress in several areas of research capacity building.

First, Several LIL participants are currently using the PhotosynQ platform as a part of their LIL-supported work, including Kelvin Kamfwa at the University of Zambia, Isaac Dramadri (at MSU with James Kelly), Isaac Osei-Bonsu (in the Kramer lab at MSU) as well as several students working with collaborators Tim Close (U.C. Riverside), Phillip Roberts (U.C. Riverside) and Phil McLean (NDSU).

Second, we are actively working towards setting up cutting edge phenotyping centers at the University of Zambia and Makerere University in Uganda. At UNZA, faculty and staff now have access to 6 MultispeQ and are actively involving the UNZA team in the redesign, validation and implementation of the new version 1.0 devices as well as the

new online analytical capacity, which will both lead to publications and help nucleate a phenotyping center at UNZA. In addition, seven undergraduate and one master's students at UNZA, and two research technicians from Zambia Agricultural Research Institute (ZARI) in the Ministry of Agriculture have received training on PhotosynQ. The six undergraduate students include five males and two female who are pursuing Bachelor of Science degree in crop science at UNZA. The two technicians from ZARI include one male and one female who work for the National Bean Breeding Program. Similarly, there are currently 3 MultispeQ instruments available for faculty and staff to use at Makerere University resulting in the initiation of four separate research projects in which nearly 7,000 measurements have been made on cowpea, groundnuts, and maize.

The irrigation system at research station at UNZA is currently being renovated and up-graded using supplemental Institutional Capacity Strengthening funds. Purchase of irrigation equipment and renovation works are underway. Once the renovations are completed the research capacity UNZA to conduct drought experiments in FY17 will be enhanced.

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

VI. Human Resource and Institution Capacity Development

(*This section is a compilation of short-term and long-term degree training activities completed by the project during the performance period. This section is intended to be independent of research capacity strengthening activities described in the previous section.)*

1. Short-Term Training

(*Provide the following information for each short-term training activity completed*.)

i. Purpose of Training: Train undergraduate students at University of Zambia and research technicians at Zambia Agricultural Research Institute (ZARI) on how to use the PhotosynQ platform to collect data from field experiments.
ii. Type of Training: Short-term training
iii. Country Benefiting: Zambia
iv. Location and dates of training: University of Zambia in Lusaka (date: 01/11/2016-01/22/2016); Zambia Agricultural Research Institute (ZARI) at Misanfu Research Station in Kasama (date: 01/25/2016-01/29/2016).
v. Number receiving training (by gender): Three females and six males.
vi. Home institution(s) (if applicable): (i) University of Zambia, (ii) Zambia Agricultural Research Institute (ZARI)
vii. Institution providing training or mechanism: University of Zambia

2. **Degree Training**

Name of Trainee: Kelvin Kamfwa
Country of Citizenship: Zambian
Gender: Male
Host Country Institution Benefitting from Training: University of Zambia
Institution providing training: MSU
Supervising Legume Innovation Lab PI: James D. Kelly
Degree Program: Doctorate
Field or Discipline: Plant Breeding, Genetics and Biotechnology
Thesis Title/ Research Area: Genetic dissection of biological nitrogen fixation in common bean using genome-wide association analysis and linkage mapping.
Start Date: August 2008
Projected Completion Date: November 2015
Training Status: Active
Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
Type of Legume Innovation Lab Support (full, partial or indirect): Full

Name of trainee: Isaac Dramadri
Citizenship: Uganda
Gender: Male
Host Country Institution Benefitting from Training: Makerere University
Training Institution: MSU
Supervising Legume Innovation Lab PI: James D. Kelly and Wayne Loescher
Degree Program: Doctorate
Field or Discipline: Plant Breeding, Genetics and Biotechnology
Thesis Title/ Research Area: Physiological studies on drought tolerance in Andean beans.
Start Date: August 2013
Projected Completion Date: September 2017
Is trainee a USAID Participant Trainee and registered on TraiNet? Yes
Training Status: Active

Name of trainee: Isaac Osei-Bonsu
Citizenship: Ghana
Gender: Male
Host Country Institution to Benefit from Training: CSIR-Crops Research Institute
Training Institution: Michigan State University
Supervising CRSP PI: Dr. David Kramer
Degree Program for training: Doctorate
Field or Discipline: Plant Physiology

Thesis Title/Research Area: Heat Stress Effects On Photosynthesis in Legumes
Start Date: August, 2015
Projected Completion Date: 2019
Training status (Active, completed, pending, discontinued or delayed): Active, indirect support

VII. Achievement of Gender Equity Goals
(*Describe progress in achieving gender equity goals set for the project during the performance period*.)

A critical component of accomplishing our gender equality goals is to ensure that PhotosynQ technologies are equally accessible to women and men. In FY 2016 we have made progress towards that goal by 1) training two female undergraduate students at UNZA and 2) identifying a female graduate student who will pursue a Master's Degree in plant breeding and seed systems at UNZA using the PhotosynQ platform starting in FY 2017, with Dr. Kamfwa as her PI.

VIII. Explanation for Changes
(*Identify and justify all project changes or inability to complete research and training activities during the FY 2016 project period, as outlined in the workplan. If specific activities have been delayed, indicate when they will be carried out in the future and confirm that sufficient funds have been encumbered to support these activities at that time. Please remember that delayed activities will need to be reported in future annual project technical progress reports.*)

During FY 2016 we were not able to complete the data management plan to ensure that PhotosynQ's data policies conform to USAID's open data policy. Scheduling conflicts made it impossible to travel to Washington D.C. to consult with USAID regarding the data management plan. We have included completing the data management plan in the FY 2017 workplan and will complete this objective prior to September 30, 2017.

IX. Self-Evaluation and Lessons-Learned
(*Discuss challenges, failures, and successes in initiating and implementing the respective collaborative research and capacity strengthening project during the FY 2013 – 2017 extension phase. Provide also a self-evaluation on the strength of the collaborative relationship among the team of U.S. and Host Country scientists participating in the project and suggestions for improving the effectiveness and productivity of the project. Share lessons learned and recommendations that might be beneficial to other projects and the Management Office in its administration of the Legume Innovation Lab program*.)

Prior to FY 2016, most of the collaborative research was undertaken in the United States (at MSU, UC-Riverside, and NDSU). This made communication between collaborators very easy. In FY 2016, Kelvin Kamfwa relocated to the University of Zambia, making communication more challenging. In addition to direct communication between collaborators, we now need to provide educational and training modules to collaborators with poor internet access and speed in Zambia and Uganda. Currently, many of our training modules are in the form of short tutorial videos. However, these videos are often not appropriate for those with slow internet connections. Therefore, the PhotosynQ team will need to re-evaluate how we deliver training and educational materials to LIL partners.

X. Scholarly Accomplishments

(*Identify all **publications**, theses and/or dissertations, presentations, professional recognitions, awards, patents, and Plant Variety Protection Certificates that evidence scholarly accomplishments by U.S. and Host Country scientists as well as degree trainees during the performance period. Please send electronic copies of publications to the MO for sharing with USAID.*)

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

Hoh D, Osei-Bonsu I, Cruz J, Savage L, Hall D, Kramer DM. 2016. The effects of temperature on photosynthetic parameters of cowpea (*Vigna unguiculata (L.) Walp.*) genotypes and relation of photosynthetic parameters and seed yields on cowpea. Poster, PhotosynQ workshop, East Lansing, MI.

TerAvest D, Yohane E, Mnthambala F, Kramer DM. 2016. Deploying PhotosynQ to enhance local pigeonpea breeding programs in Malawi. Poster, Pan-African Grain Legume & World Cowpea Conference. Livingstone, Zambia

Osie-Bonsu I, Hoh D, Cruz J, Savage L, Kuhlgert S, TerAvest D, Austic, Zegarac R, Kramer DM, 2016. Variation in chlorophyll fluorescence-derived photosynthetic parameters and SPAD of cowpea genotypes subjected to drought and flooding stress at the pod filling stage. Poster, Pan-African Grain Legume & World Cowpea Conference. Livingstone, Zambia

XI. Progress in Implementing Impact Pathway Action Plan

(At the project planning and workplan development stage, each project team prepared an Impact Pathway identifying major research outputs, users of these outputs, a vision of success, and necessary steps to achieve the vision of success. In the Impact Pathway worksheet, your project also identified strategies and an action plan to be undertaken by the project team over the 4.5 year life of the project to translate the outputs into outcomes. Please provide an update on your team's efforts in implementing the action plan and progress towards achieving the 'vision of success' as laid out in the Impact

Pathway strategy. Discuss any constraints encountered and steps taken to overcome them.)

Outputs

Output #1. Provide advanced scientific instrumentation for developing countries: The project will produce 20 MultispeQ instruments, 16 of which will be delivered to labs in Zambia and Uganda. Qualitatively, these instruments will immediately allow researchers in Africa to perform cutting edge research, enabling them to perform the work described in the proposal. In addition, we expect the capabilities of the instruments to enable researchers in HCs to initiate new research projects.

In FY 2016, we provided 6 MultispeQ devices to project partners at the University of Zambia so that they can perform cutting edge research. In the first year of having MultispeQ instruments, multiple undergraduate students have received training on the PhotosynQ platform and these same students have collected over 4,000 MultispeQ measurements.

Output #2. Capacity building through advanced phenotype-driven identification of QTLs for improving the efficiency and resilience of photosynthesis in grain legumes.

We have successfully identified phenotype-driven QTL's using both controlled conditions in DEPI chambers and using MultispeQ under true field conditions.

Output #4. Capacity building through education: Another essential component of the project is to enable researchers in HC to take possession of both the technology and the educational efforts required to use it effectively. To achieve this, we plan to engage students in the process of developing and disseminating the educational materials, giving them ultimate control of the platform and process.

We have made progress towards this output goal through the following of activities: 1) training of undergraduate and graduate students at Michigan State University and the University of Zambia and 2) developing training videos and educational modules that are available on www.photosynq.org so any user on the platform can learn how to use the PhotosynQ platform to answer research questions.

ANNEXES

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

Annex 2. Literature Cited
(*List all literature cited in the body of the technical progress report in full bibliographic form.*)