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

Lead U.S. Principal Investigator
James D. Kelly, Michigan State University, USA

Collaborating Scientists
Wayne Loescher, Michigan State University, USA
James Steadman, University of Nebraska, USA
Carlos Urrea, University of Nebraska, USA
Karen Cichy, USDA-ARS, East Lansing, Michigan, USA
Eduardo Peralta, INIAP, Ecuador
Stanley Nkalubo, NaCCRI, Uganda
Kennedy Muimui, ZARI, Zambia

Abstract
Common bean (Phaseolus vulgaris L.) is the most important grain legume consumed in Ecuador, Uganda, and Zambia. Improved bean genotypes from Ecuador have a potentially significant spinoff in adaptability to upland farming systems in East Africa. Building on international bean germplasm, but particularly on the Ecuador germplasm, an opportunity exists to develop and to deploy improved bean varieties, using a combination of traditional and the latest molecular plant improvement techniques. An improved understanding of plant traits and genotypes with resistance to multiple stresses from abiotic (drought) and biotic (root rot and foliar pathogens) sources will provide unique genetic materials for enhanced plant breeding methods and sources to study plant tolerance mechanisms. Improvements in understanding the physiology of drought and evapotranspiration and the genetics of drought tolerance in common bean and the development of effective molecular and quantitative methods for the selection of drought tolerance are needed. The development of improved bean varieties and germplasm with high yield potential, healthy root systems, improved BNF with resistance to multiple diseases, and sustained or improved water use efficiency under limited soil water conditions are needed to increase profit margins and lower production costs. The project will use QTL (Quantitative trait loci) analysis and single-nucleotide polymorphism (SNP)-based genome-wide association mapping to uncover regions associated with drought tolerance, disease resistance, enhanced BNF, and shorter cooking time. Results of this project would contribute to improved yield, farm profitability, and human resources in the host countries and the United States.

Project Problem Statement and Justification
Beans are the second most important food legume crop in Zambia and a major source of income and cheap protein for many Zambians. Most of the bean crop (62 percent) is produced on 60,000 ha in the higher altitudes of northern Zambia. Andean beans are predominant and landraces 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, including 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, reflected in the very low national yields ranging from 300 to 500 kg/ha that result in an 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, since Zambia ranks 164 out of 184 countries on the Human Poverty Index. Ecuador has the only active Andean bean breeding program and past advances made in combining different disease resistances in bush beans need to be transferred to the climbing beans that play a vital role in the farming system and livelihood of small producers. Improvements in climbing beans can easily be transferred to many African countries that grow similar seed types.

Beans are an important crop in Uganda and are grown on more than 660,000 ha of land and consumed throughout the country. They are a major source of food and income for smallholder farmers, especially women and children. The majority of bean production in Uganda is dependent mainly on the use of inferior landrace varieties that are generally low yielding due to susceptibility to the major biotic and abiotic stresses, which gravely undermine the potential of beans 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 percent of global bean production; the severity of yield reduction depends on the timing, extent, and duration of the drought. The presence of other stresses, such as high temperature, root diseases, shallow infertile soils, and climate change all intensify the problem. Improvements in current understanding of the physiology of drought and evapotranspiration as well as the genetics of drought tolerance in common bean and the development of effective molecular and quantitative methods for the selection of drought tolerance are therefore needed. Targeting specific photosynthetic (Ps) traits using phenometric tools to identify and avoid drought sensitive components of the Ps process should lead to the identification of elite genotypes important for breeding improvement. The development of improved varieties and germplasm with high yield potential, healthy root systems, improved BNF with resistance to multiple diseases, and sustained or improved water use efficiency under limited soil water conditions are needed to increase profit margins and 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.

Objectives

1. Integrate traditional and marker-assisted selection (MAS) approaches to combine resistances to economically important foliar diseases, drought, and improved BNF 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), Ecuador, and the United States.
2. Characterize pathogenic and genetic variability of isolates of foliar pathogens collected in Uganda, Zambia, and Ecuador 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.
3. Use 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.
4. Develop phenometric approaches to improving the efficiencies of breeding for abiotic stress tolerance, especially drought.
5. Institutional Capacity Building and Training for doctoral students from Zambia and Uganda, one doctoral and one MS student from the United States—all in Plant Breeding, Genetics and Biotechnology.

Approaches and Methods

We plan to conduct QTL mapping and develop molecular markers associated with drought and disease resistance and improved BNF in the Andean Diversity Panel. The pathogenic variability of isolates of foliar pathogens will be determined and identified sources of resistance to ALS, ANT, CBB, BCMV and bean rust will be identified in Andean germplasm. QTL for nitrogen fixation and related traits will be conducted using genome-wide association analysis in Andean bi-parental mapping populations. We will rely on new instrumentation and techniques now available at the Center for Advanced Algal and Plant Phenometrics at MSU to improve the efficiencies of breeding for stress tolerance, which will allow nondestructive and continuing measurements of photosynthetic properties (e.g., gas exchange and chlorophyll fluorescence), growth and plant architecture, and more detailed measurements of photosynthesis. These analyses will contribute to identifying new traits based on relationships between genotype and drought response. The acceptability of fast cooking, high mineral content will also be assessed using a pin drop (Mattson cooker) method in bean germplasm in Uganda, Zambia, and Ecuador; bi-parental mapping populations will be developed to identify QTL for cooking time. New discovered QTL will be used in breeding for all traits.

Anticipated Achievements and Outputs

- Established and evaluated (mobile) nurseries for ALS, ANT, CBB, rust, and drought and identified source of resistance in Ecuador, Zambia, and Uganda.
- Collected and characterized isolates of ANT, ALS, CBB, and Rust from different bean production regions of Zambia, Uganda, and Ecuador.
- Initiated crossing of landraces with resistant sources of ALS, ANT, CBB, and Rust in Zambia, Uganda, and Ecuador and conducted progeny screening for different for resistances.
- Identified Andean drought tolerant lines from a trial tested in Scottsbluff, Nebraska.
- Assessed the acceptability of Andean lines with superior mineral bioavailability and short cooking times and initiated crossing for genetic improvement of Andean lines with superior mineral bioavailability, short cooking time, and disease resistance and developed high throughput/ nondestructive methods for determining cooking time.
- Developed drought screening protocols (using both field and next generation phenometric-based techniques) and assembled a drought nursery to be tested in Africa and the United States.
- Characterized biophysiological (gas exchange and chlorophyll fluorescence) characteristics associated with drought resistance.
- Developed improved bush and climbing Andean beans with drought and multiple disease resistance.
- Identified more robust markers for ANT and ALS and identified QTL for enhanced BNF and drought tolerance for use in MAS.

Projected Developmental Outcomes

- New improved bean varieties with disease and drought resistance and shorter cooking times
- Release of a new Andean cranberry bean variety with superior overall performance by MSU and two superior quality Mesoamerican navy and black bean varieties by MSU and UNL.
- Release of two new Andean bean varieties by INIAP, Ecuador, and two varieties by ZARI, Zambia. These varieties would differ in seed types so the specific seed type is not yet identified.
- Relevant pathogens, such as rust, characterized in Ecuador, Uganda, and Zambia.
- The project will interface with scientists working for national programs in Ecuador, Uganda, and Zambia, who are heading up active bean breeding programs in each country. Broadening and strengthening these programs is vital to the long-term sustainability of the agricultural sector in all countries. Having the network to exchange germplasm when dealing with similar biotic and abiotic constraints promotes more rapid advancement and increases the opportunity of finding valuable genetic stocks that may result in future varieties with significant, future local impact.

Contributions to Institutional Capacity Building

Enhanced scientific capacity in Uganda and Zambia through graduate student training and short-term workshop: two PhD students for Africa, one MS student for Ecuador, and training for 16 staff (10 male, six female) in disease and pest identification in Uganda and Zambia. The project is planning to send participants to the other workshops being planned by the S01.A4 project.