FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Innovation Lab for Collaborative Research on Peanut Productivity and Mycotoxin Control

Final Report 2012-2017

Feed the Future Innovation Lab for Collaborative Research on Peanut Productivity and Mycotoxin Control

(Peanut & Mycotoxin Innovation Lab)

Final Report

(31 July 2012 – 30 September 2017)

PMIL Management Entity
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Acronyms

AFB	Aflatoxin B_1
AOR	Agreement Officer's Representative
APHIS	Animal and Plant Health Inspection Service, USA
ASU	Albany State University, Albany, GA
CAES	College of Agricultural and Environmental Sciences
CERAAS	Centre d'Etude Régional pour l'Amélioration de l'Adaptation á la Sécheresse, Senegal
CNRA	Centre National de Recherches Agronomiques, Senegal
Co-PI	co-Principal Investigator
COMESA	Common Market for Eastern and Southern Africa
CRI	Crops Research Institute, Ghana
CRP	CGIAR Research Program
CRSP	Cooperative Research Support Program
CSB+	Corn Soy Blend
CSB-P	CSB plus multiple micronutrient tablet
CSIR	Counsel for Scientific and Industrial Research, Ghana
DBS	Dried Blood Sample
EAP	External Advisory Panel
EMMP	Environmental Mitigation and Management Plan
FY2013	Fiscal Year 2013
FY2014	Fiscal Year 2014
FY2015	Fiscal Year 2015
FY2016	Fiscal Year 2016
GWAS	Genome-Wide Association Study
HACCP	Hazard and Critical Control Points
HIV	Human Immunodeficiency Virus
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IIAM	Instituto de Investigação Agrária de Moçambique, Mozambique
IITA	International Institute for Tropical Agriculture, Nigeria
ISRA	Institut Sénégalais de Researches Agricoles, Senegal
KNUST	Kwame Nkrumah University of Science and Technology, Ghana
LUANAR	Lilongwe University of Agriculture and Natural Resources, Malawi
ME	Management Entity
MoFA	Ministry of Food and Agriculture, Ghana
MSc	Master of Science Degree
MSU	Mississippi State University, MS
MUAC	Mid-Upper Arm Circumference
NaCRRI	National Crops Resources Research Institute, Uganda
NARO	National Agricultural Research Organization, Uganda
NaSARRI	National Semi-Arid Resources Research Institute, Uganda
NASFAM	National Smallholder Farmers Association of Malawi, Malawi
NBCRI	Norman Borlaug Commemorative Research Initiative
NCSU	North Carolina State University, NC
NGO	Non-Governmental Organization
NPRL	National Peanut Research Lab, Dawson, GA
PCR	Polymerase Chain Reaction
PhD	Doctor of Philosophy Degree
PI	Principal Investigator
PIIM	Peanut Industry Incubator Model
PMIL	Peanut & Mycotoxin Innovation Lab
RDA	Recommended Daily Allowance
RNAi	RNA interference
RSS	Rich Site Summary
RUSF	Ready-to-Use Supplemental Food
RUSF-P	Ready-to-Use Supplemental Food plus 200% micronutrients in pregnancy
RUTF	Ready-to-Use Therapeutic Food
SARI	Savanna Agricultural Research Institute, Ghana
SNP	Single Nucleotide Polymorphism
SPAD	Soil Plant Analysis Development
SNP	Single-nucleotide polymorphism
SSR	Simple Sequence Repeat
STN-PCR	Single Tube Nested Polymerase Chain Reaction
TNAU	Tamil Nadu Agricultural University, India
UDS	University for Development Studies, Ghana
UFL	University of Florida, FL
UGA	University of Georgia, GA
UHPLC	Ultra-High Performance Liquid Chromatography
UNZA	University of Zambia, Zambia
USAID	United States Agency for International Development, USA
USDA	United States Department of Agriculture
USDA-ARS	United States Department of Agriculture – Agricultural Research Service
WU	Washington University, St Louis, MO
ZARI	Zambian Agricultural Research Institute, Zambia

Executive Summary

The PMIL research program was organized around three primary themes: 1) genomics and breeding, 2) aflatoxin detection and nutrition, and 3) research along the peanut value chain.

Theme 1

As part of a larger collaborative initiative in the peanut research community, geneticist Peggy Ozias-Akins and partners advanced the development of a SNP chip genetic marker system and evaluated the potential for this tool to identify genetic associations with aflatoxin resistance in targeted populations in both the US and with partners in Senegal.

With joint funding from the USAID's Norman Borlaug Commemorative Research Initiative, research pathologist Renee Arias and colleagues developed an innovative potential strategy for aflatoxin control through an RNA interference strategy targeting the toxin producing *Aspergillus flavus* molds as they infect the peanut plant, before they are able to produce the toxin. Through evaluating the diversity of *A. flavus* strains from various countries, they were able to confirm the efficacy of this strategy regardless of strain.

The Integrated Global Breeding Program, led by plant pathologist Carl (Mike) Deom in collaboration with many domestic and international breeders, worked in all target countries, as well as with key programs in Uganda, Burkina Faso, Kenya and India. The achievements of these projects are numerous, and include assistance in the release of several improved varieties in the US and overseas, establishment of a new breeding program in Haiti, initiating an innovative network of young breeders in several national programs in Africa who are now sharing technology and varieties, as well as collaborating on broader regional research objectives.

Theme 2

Each of the four projects under the detection and nutrition theme was unique, but collectively are important steps towards measuring aflatoxin and its impact, and eventually to the improvement of the nutritional status of people in targeted countries, especially women and children. Haibo Yao's team at the US Department of Agriculture advanced their innovative spectral imaging strategy for low cost aflatoxin detection, completing a prototype of the "aflabox" while also exploring new areas where this technology may be disruptive in low-cost monitoring of aflatoxin in maize.

JS Wang's lab at the University of Georgia was able to develop a method to use dried blood spots to detect aflatoxin exposure in human blood. This technology will greatly improve the ability of researchers to monitor and investigate the impact of aflatoxin exposure on human health, and has already been deployed in collaboration with the Nutrition Innovation Lab.

Kumar Mallikarjunan's investigation of various detection methods and labs was able to confirm the detection limits of some novel technologies, as well as some potential issues with human error in accurate detection. One new aflatoxin detection system evaluated, an electronic tablet-based system developed by MobileAssay in the US, was determined to be as accurate as other costlier and complicated systems. Based on these results, the tablets and accompany sampling technology was deployed and used in most all of the target countries.

Finally, while pediatrician Mark Manary's study of a new Ready to Use food for malnourished mothers in Malawi was unable to produce significant birth outcomes as hoped, it did advance the knowledge of the treatment window for this important population.

Theme 3

The three large value chain projects varied greatly depending on the needs and opportunities in each country. Though different in structure, the randomized control trial in Ghana also advanced the knowledge of aflatoxin control measures in the value chain in Ghana.

In Haiti, Macdonald's team was able to follow up with advances made with NGO and private sector partners, especially related to input technologies and variety evaluations, but also expanded to collaborate with universities, including 41 students successfully completing research projects. Two surveys were completed showing significant impacts on aflatoxin awareness and yield gains through connecting with the collaborating commercial aggregation network.

In Ghana, the value chain project led by Jordan completed diverse projects from an exhaustive factorial analysis of technologies aimed at reducing aflatoxin during production, drying and storage, to more detailed projects in each of these areas, primarily led as student projects with collaborating universities. These projects also included an element of farmer education and economic analysis showing that the technologies are producing a return on investment, both financially and in aflatoxin reduction.

The randomized control trial led by Magnan produced solid data on both the impact of technologies aimed at aflatoxin reduction and the potential likelihood of adoption under various scenarios. The project showed the difficulties of both conducting field-based aflatoxin research and the formal commercialization of the sector, through high seasonal variation in infection that may create disincentives for adoption. The project also documented the peculiarities of groundnut pricing as it relates to smallholder's economic incentives throughout the season, which will also be pivotal for parties interested in more formal commercialization of smallholder production.

The Southern Africa value chain project in Malawi, Mozambique and Zambia, and the associated economic evaluation project, led by Brandenburg and Bravo-Ureta, respectively, overcame great initial challenges to establish a solid research network across universities, national programs, NGOs and the private sector. Significant results were produced in each country, from basic to applied research and from production to consumption. Much of the work was led by students, creating capacity for future research in the region.

Capacity Development

Of particular importance are the efforts all projects invested in graduate student training. More than 70 students received graduate degrees in a range of disciplines related to agronomy, food science, nutrition or public health with PMIL support. A total of 41 students received master's degrees and 19 completed doctorate degrees. Of those students, 53 studied at universities in their home country or region, further building higher education capacity within their university systems. Half of the graduate students were female. In addition to long-term training, the PMIL provided short-term training to 48 students.

Program Countries

PMIL primary target countries are Ghana, Haiti, Malawi, Mozambique and Zambia. In addition to the primary countries and the USA, PMIL has research partnerships in Burkina Faso, Ethiopia, India, Kenya, Mali, Niger, Nigeria, Senegal and Uganda.

Program Partners

PMIL works with universities and other institutions located in 15 US states (Alabama, California, Connecticut, District of Columbia, Florida, Georgia, Louisiana, Maine, Missouri, Mississippi, North Carolina, New Mexico, New York, Texas and Virginia) and 14 foreign countries (see above list). Details on the specific institutions in each US state and foreign country are provided in Appendix A.

Key Accomplishments and Lessons

Advances in genetics

Through two projects, researchers homed in on the genetics of aflatoxin resistance in peanut.

Replicated field trials were conducted in rain out shelters in Tifton, Georgia, to create conditions conducive for aflatoxin accumulation. Eight hundred inbred lines were phenotyped for preharvest aflatoxin contamination, and while none were completely resistant to contamination, one showed reduced contamination in the field and clear resistance when stored after harvest. This line will be further evaluated to explore the potential genetic basis of aflatoxin resistance and the potential to move this trait into commercially viable lines.

Taking a different genetic approach, using RNA interference, Renee Arias at the National Peanut Research Laboratory (NPRL) in Dawson, Georgia, worked to silence the gene in *Aspergillus* molds that creates aflatoxin, a strategy that no scientist had proven to be possible.

Working with researchers and graduate students from several African countries, Arias analyzed the genetic diversity of toxigenic *Aspergillus* species from Ethiopia, Kenya, Malawi, Tanzania, Uganda, Zambia and the US. Understanding the genetic diversity helps to better design the genes that are needed for RNA interference to work, and to create region-specific versions of products like Aflasafe, which work by applying atoxigenic fungi to a crop to outcompete strains that produce aflatoxin.

At the same time, work that started in 2011 at the NPRL, was brought to fruition, demonstrating that scientists can silence the aflatoxin-synthesis genes through RNA interference and actually prevent aflatoxin accumulation in peanut seeds even when they are infected with *Aspergillus flavus*.

Advances in traditional breeding

While work in the lab approached the promise to produce peanuts more resistant to the scourge of aflatoxin, traditional breeding was used to develop improved seed varieties and get them into the hands of farmers across several African nations. The program targeted breeding for disease resistance, plentiful yield, high-oleic fatty acid content, and drought tolerance; traits of interest to farmers, processors and consumers. Beyond the evaluation of new varieties, the program was also able to build capacity in national programs for continued research and make linkages to markets and seed systems to increase the availability and adoption of improved varieties and eventually to improve farmer income.

Nine varieties of the Serenut line were commercialized in Uganda, where average on-farm yields grew from 620 kg/ha in 2010 to 1000 kg/ha in 2016, without added input, simply through adoption of improved varieties.

The high-oleic Valencia peanut variety NuMex-01 was released in the US, while proposals were submitted for release of two new Valencia varieties in Mozambique – one with high oleic content and another with partial resistance to Sclerotinia and leaf diseases – developed through a long term collaboration between the two programs.

Government support and partnerships

Governments in partner countries are recognizing the work and accomplishments of researchers and farmers in their countries. For example, in Uganda, groundnut was named a priority research crop for its importance to improve livelihood, while in Ghana, the ministry of agriculture recognized farmers for the yield improvements they made with PMIL information. The farmers, nine women and two men from the Dagomba village in the Drobonso District of Ashanti region, began training in 2013, taking part in farmer field days run by PMIL's partner, the Crops Research Institute (CRI) under the Council for Scientific and Industrial Research (CSIR) in Ghana. The training sessions are held every two weeks during the growing season. Recent evidence also shows a positive spillover impact to other nearby farmers.

Breeder consortium

Through the support of PMIL, a consortium of national program peanut breeders from across Africa has begun to come together to share knowledge and germplasm. The program has worked closely with David Okello, the groundnut breeder in Uganda, who completed his education with support from the Peanut Collaborative Research Program in the 2007-2012 cycle and continues to be a lynchpin in the functioning of the consortium. The group in East and Southern Africa communicates regularly and develops proposals jointly to take advantage of regional opportunities.

Production packages

Across PMIL partner countries, researchers have evaluated production packages and are beginning to establish traing tools that help farmers make decisions about planting date and density, weeding practices, inputs and harvest date to maximize the volume and quality of the harvest.

In Ghana, work to compare farmer practices and improved practices at the village level gave clear results about how various interventions work alone or together to improve yield and reduce pre- and post-harvest aflatoxin contamination.

In Malawi, much of that work was done by Lydia Mkandawire, an extension agent who took leave from her job to pursue a master's degree. Mkandawire showed in two years of field trials that planting and harvest date have a large impact on yield, which may help farmers reprioritize activities, knowing there is a clear benefit. This research also showed that planting a denser stand also pays off in harvest size. Mkandawire quickly adopted new practices on her own farm, and because she is an extension agent and farmer herself, Mkandawire can influence growers in her area directly.

Understanding economic incentives

Farmers everywhere want the highest price for their crop, but when offered a premium to sell low-aflatoxin groundnuts shortly after harvest, many farmers in Ghana declined. In fact, less than 5% would sell two to three months after harvest, showing that creating incentives for farmers to grow, dry and sell low-aflatoxin groundnuts may be more complicated than researchers previously assumed.

The findings show that while some farmers sell their crop immediately, some were holding out for a higher price and many farmers wanted to keep their crop to sell throughout the year when they need money. Any program that wants to aggregate the crop and reduce the risk of aflatoxin contamination must take into consideration the way some farmers use groundnuts as a type of savings. This important lesson will help in the future to design programs that both serve the farmers' financial interests, while providing for efficiency in aggregation and storage.

Food safety with small processors

Research projects in Malawi and Ghana homed in on the sources of contamination in local peanut products – peanut butter and flour in Malawi, peanut paste in Ghana – and through training of the producers, researchers were able to demonstrate improved quality of products that can meet market standards.

In the case of peanut butter in Malawi, master's student Tchiyiwe Moyo-Chunda, evaluated samples on the market in Malawi and found problems with quality, as well as fecal coliform and aflatoxin contamination. After taking a training program Moyo-Chunda designed to address those quality and safety issues, one local processor was able to gain government accreditation, launch a commercial brand of peanut butter and pursue a plan to employ more women in the business.

With groundnut flour, the research of Chikondi Magomba and Tiwongwe Longwe helped create a national standard for groundnut flour, which is now in use by the Malawi Bureau of Standards, further showing evidence of the importance of research and government collaboration.

Capacity Building

Throughout the 2012-2017 program, more than 70 students received graduate degrees in a range of disciplines related to agronomy, food science, nutrition or public health with PMIL support. A total of 41 students received master's degrees and 19 completed doctorate degrees. Of those students, 53 studied at universities in their home country or region, further building higher education capacity within their university systems. Half of the graduate students were female.

In addition to long-term training, the PMIL provided short-term training to 48 students. While all of these students contributed to PMIL's work in some way, they included a wide spectrum of disciplines and level of expertise – from Ethiopian PhD candidate Abdi Mohammed Hansen, who completed research at the NRPL and returned to take a teaching position at Haramaya University, to 35 Haitian undergraduate students who interned with PMIL partner Meds & Food for Kids as part of their thesis completion in agronomy.

In some cases, students were already working professionals, giving their studies more immediate impact. In Malawi, extension agent Lydia Mkandawire took temporary leave from her career to complete her degree at Lilongwe University of Agriculture and Natural Resources.

In other cases, different entities with complementary or similar goals came together through a student's work. In Mozambique, Eduardo Mondlane University (EMU) and the Ministry of Agriculture's Institute of Agricultural Research (IIAM) worked together in a new collaboration that likely will lead to increased opportunities for both in the future. While working toward a master's degree in agronomy funded by RUFORUM at EMU, student Emmanuel Zuza (who is Malawian) worked with IIAM to collect data in this research with yield and aflatoxin contamination under planting and harvest timelines.

Research Program Overview and Structure

The Feed the Future Innovation Lab for Collaborative Research on Peanut Productivity and Mycotoxin Control (Peanut & Mycotoxin Innovation Lab, PMIL) aims to increase the productivity and profitability of peanut production for smallholder farmers and to reduce the negative impacts of mycotoxin contamination along the value chain of peanut and other crops in five Feed the Future countries – Haiti, Ghana, Malawi, Mozambique and Zambia. The research program is organized into three main themes: (a) peanut germplasm development, (b) mycotoxin detection and nutrition studies, and (c) peanut value chain interventions to increase quantity, decrease mycotoxin contamination and enhance economic returns to smallholder farmers. Each project is coordinated by a Principal Investigator located at a US university or USDA-ARS research station, with collaborators in the US, one or more of the target Feed the Future countries, as well as other relevant countries. All projects started in the second year (2014) after the award to the University of Georgia, and all but two continued the entire length of the award (September 2017). Project B3 (Aflatoxin in Peanut and Peanut Products: Comparative Study on Analytical Methods for Detection of Aflatoxin) was completed in 2015 and project B4 (Randomized Controlled Trial of the Impact of treating Moderately Malnourished Women in Pregnancy) in 2016.

Research Project Title	Project Investigator	Lead Institution
A. Peanut Germplasm Development		
A1. Translational Genomics to Reduce Pre-harvest Aflatoxin Contamination of Peanut	Peggy Ozias-Akins	University of Georgia
A2. Silencing of Aflatoxin Synthesis through RNA Interference (RNAi) in Peanut Plants	Renee Arias	USDA-ARS National Peanut Research Laboratory
A3. An Integrated Global Breeding and Genomics Approach to Intensifying Peanut Production and Quality	Carl Deom	University of Georgia
B. Mycotoxin Detection and Peanut Nutritional Studies		
B1. AflaGoggles for Screening Aflatoxin Contamination in Maize	Haibo Yao	Mississippi State University
B2. Development and Validation of Methods for Detection of Mycotoxins Exposure in Dried Spotted Blood Samples	Jia-Sheng Wang	University of Georgia
B3. Aflatoxin in Peanut and Peanut Products: Comparative Study on Analytical Methods for Detection of Aflatoxin	Kumar Mallikarjunan	Virginia Polytechnic Institute and State University
B4. Randomized Controlled Trial of the Impact of Treating Moderately Malnourished Women in Pregnancy	Mark Manary	Washington University - St. Louis
C. Peanut Value Chain Interventions		
C1. Production to Consumption – Technologies to Improve Peanut Production, Processing and Utilization in Haiti	Greg MacDonald	University of Florida
C2. Using Applied Research and Technology Transfer to Minimize Aflatoxin Contamination and Increase Production, Quality and Marketing of Peanut in Ghana	David Jordan	North Carolina State University
C3. Producer and Consumer Interventions to Decrease Peanut Mycotoxin Risk in Ghana	Nicholas Magnan	University of Georgia
C4. Aflatoxin Management Interventions, Education and Analysis at Various Steps Along the Peanut Value Chain in Malawi, Mozambique and Zambia	Rick Brandenburg	North Carolina State University
C5. Productivity and Profitability Growth in Peanut Production: A Farm Level Analysis in Malawi, Mozambique and Zambias	Boris Bravo-Ureta	University of Connecticut

The following section presents the key achievements for each project, along with the technologies considered ready for scaling up and out, future research needs, and the lessons learned during the project life. Summaries of these were presented on a country basis above. Further details on the achievements are available in the annual reports for the PMIL project available on the PMIL website (pmil.caes.uga.edu) and the USAID Digital Experience Clearinghouse (dec.usaid.gov).

A. Peanut Germplasm Development

Project A1. Translational Genomics to Reduce Pre-harvest Aflatoxin Contamination of Peanut

The goal of the project was to associate molecular variation with resistance to pre-harvest aflatoxin contamination and other traits on a genome-wide scale and to begin to utilize this information in breeding programs. To achieve the goal, both genotyping and highly replicated phenotyping of genetic resources and populations for aflatoxin contamination were pursued. Genotyping with genome-wide SNP (single-nucleotide polymorphism) markers was enabled by peanut genome sequence information, both from cultivated tetraploid genotypes as well as diploid progenitors of the tetraploid. Genetic populations were developed in India, Senegal and the USA. Phenotyping was done under controlled field conditions in Nigeria, Ghana, Mali, Senegal and the USA.

Achievements

Phenotyped over 800 lines of peanut for preharvest aflatoxin contamination in replicated field trials. Each year, 180-200 lines of peanut were planted in replicated plots in rainout shelters in Tifton, GA, while 30-100 lines were tested each year at various ICRISAT locations in Africa, and approximately 100 introgression lines were tested over multiple years in Senegal. While no line was completely resistant to aflatoxin contamination, one line (ICG 1471) demonstrating reduced levels of field contamination in Africa and the US and clear post-harvest resistance (Korani et al. 2017). This line has been used for gene expression studies (Korani et al. submitted) and development of a biparental population that eventually can be used for studying genetic components underlying the trait. This line also was one of 8 parents in the MAGIC population developed by ICRISAT for which 3,000 MAGIC lines in the F_6 generation are available at ICRISAT for further yield evaluation. Two of the chromosome segment substitution lines (CSSL) developed by CERAAS in Senegal also show promise for in vitro and field resistance, but additional testing will be necessary to confirm resistance.

Genotyped all lines evaluated for aflatoxin contamination using genotyping-by-sequencing methods and applied computational methods to identify allelic diversity. Genotyping-by-sequencing methods were tested for genotyping tetraploid *Arachis*; however, accurately identifying single nucleotide polymorphisms (SNPs) with low sequence coverage from these complex polyploids was problematic. Therefore, emphasis was placed on designing a SNP array. ICRISAT selected the Affymetrix platform and UGA provided the genome skim sequence from multiple accessions and computational expertise to design an Affymetrix Axiom_Arachis1 array. This array was extensively used to characterize diploid, tetraploid and introgression lines relevant to the project. It resulted in empirical data that were used by UGA with machine learning tools to develop more robust computational methods for calling SNPs from tetraploid peanut. The Axiom_Arachis2 array designed near the end of the project was tested with project materials and shown to double the output of polymorphic SNPs for tetraploids.

Applied statistical methods to test for significant associations between genomic regions and preharvest aflatoxin contamination and other traits of interest. Although a variety of statistical methods have been applied to test for associations with specific loci, the data suffer from 1) natural variation in aflatoxin contamination in spite of attempts to control environmental conditions to the extent possible, and 2) infrastructure and resources to perform large-scale testing of populations over multiple years. No statistically significant associations were detected for field-grown materials although in vitro results could detect genotypic differences and potentially could be used across populations to identify genetic components. Applying statistical methods to gene expression profiling of single contaminated or uncontaminated seeds both pre- and post-harvest increased knowledge of pathways and gene networks that may be involved in aflatoxin contamination (Clevenger et al. 2016; Korani et al. 2017 submitted) and will be informative for developing testable hypotheses for gene action.

Developed breeding tools based on the above research results and disseminated information on implementation of discoveries for breeding to programs in Feed the Future countries through workshops and training opportunities. While no reduced aflatoxin contamination quantitative trait loci were discovered as yet, the genotyping array, designed and tested with US and African breeding materials as well as interspecific hybrid populations, is already proving to be valuable for establishing marker associations with other traits, particularly disease resistances. African breeders are aware of the current status and are eager to test the diversity of their genetic materials using this genotyping resource.

Technologies for Further Scaling and Adoption

- SNP sequences are available in the array publication.
- Affymetrix Axiom_Arachis2 array is now commercially available at the same negotiated rate as for this project. The global peanut community at large is beginning to use the Affymetrix Axiom_Arachis2 array.
- Extensive analysis of the CSSL population by peanut researchers globally in partnership with ISRA/CERAAS.

Future Research Needs and Priorities

- Extensive genotyping of global peanut germplasm using the latest Affymetrix Axiom_Arachis2 array and making the data publicly available would enable the application of genomic information in peanut genetics and breeding.
- Design and implementation of phenotyping of a large array of materials for numerous traits would provide the necessary trait-marker associations required for breeding applications.
- Continuous training and support to breeding programs globally in the use of genomic information and high-throughput phenotyping technologies would enable breeders to accelerate the development of improved varieties.

Lessons Learned and Changes Made in Project Objectives

- The use of GBS in cultivated peanut germplasm is not as cost-effective or high-yielding as array genotyping given the low level of SNP polymorphisms that can be detected even with an improved SNP calling pipeline and the amount of missing data encountered.
- Phenotyping for aflatoxin contamination is highly susceptible to type-II error or identifying a line as resistant because it escaped contamination. Although we apply pressure (inoculation, drought, heat) to minimize escapes, contamination remains highly variable, making genotypic associations difficult without numerous years of phenotyping data.

- Some peanut breeders are eager to embrace new genomic technologies, but there is a gap between the generation of genome-wide data specific to each breeding program and application of genotyping data to selection for improved cultivars. The best way to address this gap (exists for US as well as developing country breeders) needs to be discussed.

Project A2. Silencing of Aflatoxin Synthesis through RNA Interference (RNAi) in Peanut Plants

The overall goal of this project is to use RNA interference (RNAi) to reduce aflatoxin contamination of peanut seeds. The research has two main objectives, 1) develop RNA interference (RNAi) technology to reduce/eliminate aflatoxin accumulation in peanut (mainly funded by Feed the Future-NBCRI); and 2) analyze the genetic diversity of aflatoxigenic *Aspergillus* species in sub-Saharan African countries (Ethiopia, Kenya, Malawi, Tanzania, Uganda and Zambia) and the USA, that will allow adapting the RNAi technology to each geographic area (mainly funded by PMIL). The first objective is the most challenging: first, because it had never been demonstrated that RNAi produced in a plant, could silence aflatoxin-synthesis genes in the fungus *Aspergillus*; and second, because the technology to prove this concept, including how to test its effectiveness without performing extensive and multi-year field trials, had to be developed within this project. The second objective, though apparently straightforward, required developing adequate molecular tools for the work. These tools had to be effective, doable at a reasonable cost, and in addition they required logistics, permits and research agreements for work that extended across many countries. Once the proof of concept in the use of RNAi against aflatoxin is demonstrated, and the predominant genotypes of aflatoxigenic *Aspergillus* are identified in each geographic area, the technology will be transferred to and adapted for each region.

Achievements

Established single seed assay for measuring aflatoxin contamination in peanut. A method was developed and published for the single-peanut-seed challenging and aflatoxin analysis by ultra-high performance-liquid chromatography (UHPLC) evaluates the effectiveness of RNAi (RNA interference) to prevent aflatoxin accumulation on RNAi-transformed seeds. The method was recently used for a research group in India (Kumar et al. 2017) to test their RNAi-transformed peanuts.

Produced first transgenic peanuts containing RNAi genes that reduced aflatoxin contamination. Under this project, work on RNAi technology to control aflatoxins in peanut that had started in 2011 at the NPRL was brought to fruition, demonstrating that expression of RNAi fragments in peanut plants to silence aflatoxin-synthesis genes, can actually prevent aflatoxin accumulation in peanut seeds upon infection with *Aspergillus flavus*.

Characterized small RNAs produced in peanuts. In addition to demonstrating RNAi-mediated prevention of aflatoxin accumulation in peanuts, the group began to characterize and publish the type of small RNAs produced in peanut plants. These findings have also submitted for publication.

Developed a workflow for studying the *Aspergillus* population genetics. Work at the NPRL allowed for the fast development of a “workflow” in the population genetics of *Aspergillus*, the fungi responsible for the accumulation of aflatoxins in seeds. The workflow is now published, and uses the genetic fingerprinting of hundreds of *Aspergillus* isolates using insertion/deletion (InDel) markers, and the most abundant genotype representatives were selected for whole-genome sequencing. The sequencing information can be used to design more effective RNAi-targeted sequences to control aflatoxin accumulation on specific geographic areas. This workflow, initially developed using samples from USA, has now been applied to samples from Ethiopia, and the work was submitted for publication.

Technologies for Further Scaling and Adoption

- The method of single-seed challenge and analysis by UHPLC to determine susceptibility to aflatoxin accumulation has been validated. We have applied this technology to seeds of wild peanut species, and the manuscript was submitted for publication.
- The workflow for the study of genetic-diversity of aflatoxigenic and non-aflatoxigenic *Aspergillus* isolates has been published and can be used by researchers to better understand this diversity and its impact.
- The molecular constructs harboring fragments of aflatoxin-synthesis genes of *Aspergillus* were described and these fragments can be introduced into plants as a way of vaccination against aflatoxin accumulation.

Future Research Needs and Priorities

- Further study and understanding is needed on the generation, persistence, movement and concentration of small RNAs being produced inside peanut plants.
- The development of RNAi-transformation in countries that are GMO (genetically-modified organism)-friendly should be continued in order to provide "safer" peanut seeds for human consumption. This work will continue in collaboration between NPRL and Kenyatta University, Kenya, beyond the termination of the PMIL project.
- The "workflow" for genetic diversity of *Aspergillus* should be applied to areas of the world where aflatoxin contamination is a health threat.

Lessons Learned and Changes Made in Project Objectives

- There is a great need for the transfer of skills, from simple technologies to help farmers in Sub-Sahara African countries, to current laboratory tools to build the next generation of scientists in those countries.
- Investing even short time in providing training to foreign students can have a significant impact in their careers and their countries. Abdi Mohammed Hassan, the PhD student who received training at USDA-ARS NPRL, Dawson, GA, has now been hired by Haramaya University, Ethiopia as an Assistant Professor.

Project A3. An Integrated Global Breeding and Genomics Approach to Intensifying Peanut Production and Quality

The overall goal of this project was to use conventional and molecular breeding to enhance the productivity, quality and marketability of peanut in the US and Feed the Future target countries. The research focused on intensifying the biotic resistance, abiotic tolerance and quality aspects of peanut varieties through partnerships between US and target country breeding programs. Biotic stresses include resistance to economically important pathogens and pests, such as leaf spots, groundnut rosette and groundnut leaf miner, while the primary abiotic stress addressed was drought, through tolerance and avoidance, traits that factors into mitigating aflatoxin contamination. The breeding programs also focused on value added traits, including high oleic fatty acid content (nutrition and shelf-life), increased micronutrient density (iron and zinc), high oil content (cooking oil and paste/butter) and large seeds (edible market). Outreach programs were used to stress technology transfer and the value of new cultivars and considerations for utilizing appropriate crop-management strategies. Considerable resources were directed to host countries for capacity building, including student training, continuing education for local scientists and limited infrastructure improvements. As advanced varieties became available, they were distributed to other PMIL target country collaborators and PMIL value chain projects for evaluation as well as other developing countries that request the material.

The outcomes of the research included increased yields and increased quality of new cultivars. Secondary benefits included improved peanut value chains, increased food security, better nutritional and dietary outcomes and increased income throughout PMIL target countries as well as other developing countries. Capacity building resulted in increased in-country knowledge, expertise and improved infrastructure, building a foundation to continue improving peanut yields and quality.

Achievements

The research in this project was conducted primarily as collaborations between the national breeding program in a target country and a US breeding program. Efforts were made to establish regional approaches to breeding, and to encourage sharing of germplasm, knowledge and technologies.

Burkina Faso (with Texas A&M)

- Submitted a proposal for release of two leaf spot resistant peanut varieties, one erect, one runner from populations begun in Texas. The varieties are named BF Nagouri 1 and BF Nagouri 2, and are significantly more resistant and have higher yields than the check varieties.
- Several leaf spot-resistant lines supplied by ICRISAT yielded more than 2 metric tons per hectare. GRD-resistant materials did not yield well, and were susceptible to leaf spot.
- A six-parent diallel cross was evaluated in the field. Parents were also evaluated in detail for phenotype and for SNP differences.
- Approximately 200 high-oleic Spanish lines developed in Texas from a high-oleic Texas Spanish variety and a leaf spot-resistant Ghanaian variety are being multiplied prior to testing.
- Evaluated ICRISAT drought and aflatoxin tolerant lines and US peanut minicore accessions in initial field trials. Several accessions have been promising in individual tests, but combined analysis of data across years is needed to determine if there are any consistent differences warranting a release.
- Conducted field days to introduce advanced breeding lines to farmers, particularly women farmers who are participating in planting and observation of breeding lines. Varieties currently being released were preferred by women who examined the plots.

Ghana (with Texas A&M)

- Compiled a dossier required for release of two leaf spot-resistant peanut varieties, one of which is high oleic, and one peanut line with resistance to aflatoxin contamination, developed originally by ICRISAT.
- Several leaf spot-resistant lines supplied by ICRISAT yielded more than 2 tons per hectare. Further evaluation is needed to determine whether any lines can be released as new varieties.
- Approximately 200 high oleic Spanish lines developed in Texas from a high-oleic Texas Spanish variety and a leaf spot-resistant Ghanaian variety were multiplied in Ghana and are now available for field trials.
- Conducted demonstration plots at eight sites reaching more than 700 farmers, to introduce leaf spot-resistant varieties and advanced breeding lines.

Haiti

- Collaborating researchers at University of Florida identified 15 high-yielding Bolivian landraces with ELS resistance.
- Trained the new in-country plant breeder, Dr. Raphael Colbert, and transferred 40 breeding lines and 15 Bolivian lines to Dr. Colbert for testing and selection. Dr. Colbert has previously worked primarily on common beans, but he and his team now have proven experience in generating quality data to evaluate peanut lines in Haiti and are integrating with the Value Chain research team.

Malawi (with ICRISAT)

- Evaluated advanced lines in participatory variety selections, which will assist in the release of drought-tolerant lines in Malawi. Some of the New Mexico State University lines with high oleic ratios show a great potential for release in Malawi as well.
- Trained 30 research technicians and extension staff on groundnut production and research.
- Produced and distributed extension circulars for the seven newly released groundnut varieties, Chitedze Groundnut (CG) 8, 9, 10, 11, 12, 13 and 14. Seed for these varieties was multiplied under partnership with a private sector seed producer.
- Developed new partnerships with private seed companies and other industries in the groundnut value chain to increase availability of improved varieties and gather feedback on market preferences.

Mozambique (with New Mexico State University)

- One high oleic Valencia peanut variety NuMex-01 was released in 2014 in USA.
- Proposals were submitted for release of two Valencia peanut accessions as new varieties in Mozambique, one with high oleic content and another with partial resistance to Sclerotinia and leaf diseases.
- Phenotyped two mapping populations (Valencia C × ICGV 7243 and Valencia C × JUG 03) for traits associated with drought tolerance at the ICRISAT Lysimetric facility in India. Both populations were also genotyped using the Affymetrix Axiom_Arachis2 array.
- Phenotyped recombinant inbred lines, predominantly with Valencia characteristics, for the high oleic trait and validated these lines using two SNPs associated with high oleic trait in peanut.
- Two graduate students from Mozambique completed their master's degree in plant breeding at Khon Kaen University, Thailand, under a previous collaborator of the Peanut CRSP program.

Uganda (with University of Georgia)

- Released 9 varieties (Serenuts 6-14) with various market and agronomic traits, are now commercialized in Uganda.
- Four popular landraces (Acholi white, Erudurudu, Gwerinut, Igola) were crossed for improved resistance traits and yield and are being re-introduced to the communities for evaluation and tested nationwide for possible countrywide adoption and release.
- Four lines (SGV0023, SGV002, SGV0053, SGV0084) have been developed with groundnut leaf miner tolerance. A groundnut leaf miner brochure was prepared and over 2000 copies printed and distributed. A related poster was also prepared and printed and was displayed during fairs, shows and trainings.
- Over 100 breeding lines with resistance to multiple pests and diseases were developed.
- Shared germplasm with NARS in Burkina Faso, Ethiopia, Ghana, Haiti, Malawi, Mozambique, Senegal, South Sudan, USA, and Zambia.

- Assisted with capacity development of groundnut breeding programs through training and crossing of breeding lines from Zambia, South Sudan and New Mexico State University for Groundnut Rosette Disease (GRD) resistance, yields, maturity (early to medium) and drought.
- Helped establish the capacity for groundnut variety improvement in South Sudan through successfully training a MSc graduate student, who is now the groundnut breeder for the national program. Seven varieties were developed for South Sudan by crossing local varieties with improved varieties with traits for GRD and leaf spot resistance and short to medium maturity with high yield.
- Renovated hybridization unit (greenhouses) which had been dilapidated since 1974
- Small irrigation facility (4 hectares) installed at NaSARRI to aid early generation seed multiplication and facilitate drought phenotyping
- Over 50,000 farmers trained with beneficial multiplier effects to nearby communities
- Over 30,000 dissemination materials (factsheets, brochures, books/manuals, pocket folders, pull-up banners, documentaries, and cartoon animations) produced, printed and distributed during training, field days, and agricultural shows.

Zambia (with ICRISAT)

- Acquired 35 GRD resistant lines from Uganda program for testing and potential release in Zambia.
- Acquired six high oleic varieties from New Mexico State University and 13 nutrient-dense varieties (Zn, Fe) from ICRISAT which are being evaluated and used to develop locally adopted varieties.
- Two GRD-resistant varieties submitted to variety release committee for testing and release.
- Aphid rearing and screen house renovated at Msekera Research Station.
- Local land race varieties sent to Uganda to cross with GRD-resistant varieties and are now at F_2 stage.
- 76 lead farmers (24 women and 52 men) trained in groundnut production; 10 extension (five women and five men) workers trained in selected agriculture camps; 337 women and 443 men contacted during on-farm field days at the Farmer Training Center, and 531 women and 1142 men at on-station field days.
- Over 6000 informational materials (brochures, posters, etc.) printed in the local language and distributed to farmers and other stakeholders.

Texas

- Completed the development of Spanish populations to combine drought tolerance and high oleic fatty acid content, and large seeds and high oleic fatty acid content.
- Introduced alleles for high oil content (more than 60% total oil content) from wild species. Five BC_2 hybrids are being seed increased for evaluation of oil content and quality and backcrosses made with these five lines to a high yielding cultivated line.
- Proposal accepted for the release of a high-oleic Valencia variety in Texas. The variety, TAMVal OL, out-yielded the standard Valencia check variety, New Mexico Valencia C, by 25% in extension trials, and earned an estimated additional $82 per acre.
- SSR markers for field response and yield were identified using the US minicore collection. Six SSRs were validated for yield in two F_2 populations. SSR-based QTLs for resistance to ELS, LLS, and rust were identified. KASP-based markers were developed for the high oleic trait and are being used for selection.

- 31 QTLs for domestication-related traits were identified in an A-genome diploid population. QTL analysis underway of the BC_3F_6 TxAG-6 x Florunner population using leaf spot and rust data Texas, Burkina Faso and Ghana
- The ICRISAT minicore was released from quarantine and selected lines increased.

Technologies for Further Scaling and Adoption

Ghana

- Newly released high oleic Spanish variety

Malawi

- The new CG releases have been multiplied sufficiently for large-scale seed production and evaluation in farmer trials.

Mozambique

- Two new releases of Valencia peanuts are registered with IIAM.
- Large-scale seed multiplication of two Valencia lines, 309-Red and 309-Tan, are underway at Namapa research station.
- Advanced breeding lines are ready for participatory evaluation by farmers.

Uganda

- Two improved peanut lines already released and four more prepared for release in 2018.
- Four groundnut leaf miner tolerant lines with high yields ready for testing at multiple locations.
- Dissemination materials developed (books, flyers, brochures, animations) can be shared and adopted within and outside Uganda.

Zambia

- Double row planting at 60cm spacing between ridges should be promoted for farmers.
- ICGV SM 01711 is ready for further seed production and adoption by farmers.

Future Research Needs and Priorities

Ghana and Burkina Faso

- Priority traits for selection in West Africa include yield, resistance to leaf spots, tolerance to drought, and incorporation of high oleic fatty acid content.
- Increased incorporation of markers into selection programs.
- Provision of needed facilities and equipment, including improved storage facilities to prevent losses from insects and rodents, greenhouse facilities, and vehicles to replace current ones as they wear out.
- Provision of equipment for performing field responses to water deficit stress.
- Incorporation of Senegal into the breeding program. Senegal was originally part of the project, but was dropped due to reduced funding availability.

Haiti

- Field trials indicated that introduced improved varieties have a great potential to reduce the yield gap over the local landraces, however, traits of the local landraces (market acceptance, seed vigor, yield consistency, short duration) suggest that crossing for improved traits may also be an appropriate strategy.

Malawi

- More high yielding varieties with traits preferred by markets (zinc, high oleic content, total oil content, confectionary nuts)
- There is need to strengthen further the seed systems from breeder to consumers/farmers.
- Strengthening capacity of the DARS – in terms of storage facilities for seed, irrigation facilities, training of technicians involved in breeding. Seed systems needs to be strengthened by linking breeders, seed producers, manufacturers and all stakeholders for an increased groundnut productivity.

Mozambique

- Continue generating new breeding populations and advanced varieties adapted to local conditions, combining high oleic, drought tolerance, and resistance to rosette and late leaf spot in Spanish/Virginia bunch botanical types.
- Continue phenotyping of two RILs (Valencia C × Jug 03 and Valencia C × ICG 7243) under managed stress trials at ICRISAT Patancheru, India, Texas, USA, and under rain-fed conditions in Mozambique.
- Identification and validation of SNPs and QTLs associated with drought tolerance and integrate marker-assisted breeding to select for enhanced drought tolerance.
- Identify genetically diverse and agronomically beneficial GRD resistant germplasm lines for use in breeding and genomics of peanut.

Uganda

- Climate smart research: drought (phenotyping, genotyping, remote sensing and imagery), maturity and high yields.
- Aflatoxin Research: awareness, mitigations.
- Nematology research: species diversity, resistance breeding (conventional and molecular).
- Specialty groundnuts and products: high oleic research, nutrient dense groundnuts (Iron, Zinc), confectionery types.
- Support for molecular breeding: markers for traits, breeding management software, access to genomic technologies.
- Seed systems: Early generation seeds multiplication to supply the Quality Declared Seeds and grain markets, local seed production strategies
- Germplasm sharing with NARs and CGIARs across the region.
- Capacity building: Human capacity (in all disciplines), Infrastructure (Irrigation, Cold storage, Screen houses, Glasshouses, Incubation hubs, Transport).

Zambia

- Massive new variety promotions though demos and media adverts.
- Intensive seed multiplication program to make seed available to stakeholders.
- Start of community seed bank program to help popularize and distribute new varieties to farmers.
- Glasshouse house and cold room construction to help with breeding program.
- Create market linkages for farmers.

Lessons Learned and Changes Made in Project Objectives

Ghana/Burkina Faso

- Developing Spanish high-oleic populations requires unusually large populations because of the two-gene recessive nature of the high oleic trait. Effectively, we have had to select high- and mid-oleic F_2 seeds, and perform further selection in the F_3 generation, and increase to the F_4 generation.
- Seed transfer for oil or marker analysis is relatively easy. Quarantine is not needed to import crushed seed or seed chips into the US for oil or marker analysis.
- Joint regional meetings of co-PIs is beneficial for exchanging ideas and materials, and enhancing collaborations.
- Improved storage and greenhouse facilities are needed to prevent loss of materials from rodents and insects.
- Faster turnaround of sub-awards is needed to avoid funding loss due to unspent funds. Also, there is a need for education of university grants offices in what USAID does and does not require, to avoid unnecessary paperwork or delays, avoiding errors in wire transfer of funds, or in complex budgeting for awards.

Haiti

- The environmental variability presented by the various localities in Haiti makes breeding and selection outside of Haiti much less effective than in-country breeding and selection.
- Valencia peanuts are preferred over long-duration varieties because their short growing season allows for double cropping in a single rainy season. This helps the growers to get paid twice, even with lower yields, and reduces their risk of total crop failure while waiting for the longer duration varieties to mature.

Malawi

- The project assisted in strengthening the Malawi's groundnut improvement program being able to conduct trials, seed multiplications, demonstrations and field days, and also in facilitating collaboration with other scientists and sharing of germplasm. Potential genotypes for release have been identified and some will also be used in breeding programs. However, information on traits needed by farmers and their markets needs to be sourced before a breeding program is initiated for successful adoption of developed varieties. In Malawi, on-farm demonstrations and participatory variety selections have helped to give feedback to scientists on what to focus on. Involvement of the private sector has also been very crucial in further strengthening varietal development and provision of early generation seed.
- In Malawi, one the most common varieties grown is CG 7 which was released in 1990 but still gaining popularity though flawed (not resistant to GRD). There are several new varieties which have recently been released and some are currently at the of the pipeline for release. Although, farmer adoption of new varieties is a slow process it can be enhanced by involving farmers and all other stakeholders in the groundnut value chain through the process from cultivar development to the markets.

Mozambique

- Farmer-preferred traits such as ease in harvest and shelling needs to be incorporated in new varieties.
- GRD resistance and resistance to soil-borne diseases is a must for the success of Valencia peanuts in Mozambique.

Uganda

- Farmer Participatory Variety Selection (FPVS) have been instrumental for identification and adoption of new varieties by farmers.
- Limited commercial perspective of groundnuts seed hinders large scale participation of private sector seed companies.
- Strengthened infrastructure and human capacities critical for generation of accurate data and research success.
- Involvement of NGOs and the private sector increases adoption and commercialization of groundnut technologies.
- Collaborative research which is aligned to existing government programs aids implementation and generates more success. Sharing of materials and experiences among NARS and their scientists is key in varietal development. We experienced this when we hosted 6 Breeders in Uganda.
- Linkages with other stakeholders: we formed a multi-stakeholder platform comprising of major stakeholder in groundnuts research and Development value chain. The platform is helping us do an analysis on partnership, seed demand, supply and market intelligence.
- Leveraging of funds from other development partners: This proved to be sustainable as some are complementary and continue from where AGRA funding ending. Such funding initiative includes Tropical Legume III and Peanut Mycotoxin Innovation Lab of the USAID

Zambia

- Improved seed availability still remains a big challenge in groundnuts .
- Farmers' link to markets is not well developed or formalized.
- Awareness programs should be intensified on aflatoxin and its mitigation measures .
- Need to identify more partners in the seed business to help with uptake of new technologies.

B. Mycotoxin Detection and Peanut Nutritional Studies

Project B1. AflaGoggles for Screening Aflatoxin Contamination in Maize

Aflatoxin contamination in maize and peanut is a major food safety issue worldwide. The problem is of special importance in African countries because these crops, among others, are staple foods. A primary limitation to controlling ingestion of contaminated food in these countries is the lack of affordable and feasible methods for farmers on small village farms to screen for aflatoxin contamination. Due to the high cost associated with any existing aflatoxin detection methods and the need for sample processing and detection, there is an urgent need to develop portable, rapid, and non-destructive technology for aflatoxin detection in maize and peanut for these farmers. Therefore, the goal of the project was to develop portable, fluorescence spectral-based technology for rapid and non-destructive aflatoxin detection in maize, and possibly peanut. Two prototype detection devices for this purpose were developed during the project.

Achievements

Two portable devices were developed: (1) a low-cost, image sensor based fluorescence imaging prototype, and (2) a human vision based goggles prototype for aflatoxin detection.

A major effort in the design of the low cost imaging sensor prototype (Figure 1) was the development of the Android app (AFsort). The functions of the AFsort are 1) to take fluorescence images, 2) to process image for contamination detection, and 3) to display the results. The blue and green bands in the image were used in the detection algorithm. The sample tray can handle 50 grams of maize kernels. The operation procedure was defined as a sorting process. In this approach, a sample was first imaged to identify contaminated kernels. The identified kernels were then sorted out from the rest of the (clean) sample. To evaluate the results, both parts of the same sample, contaminated and clean, were chemically analyzed to determine the aflatoxin concentrations. The chemical analysis included fluorometry and the AflaTest immuno-affinity columns from VICAM.

The prototype portable aflatoxin contamination detection device employs a tablet for fluorescence-imaging maize samples excited with a built-in high power UVLED array.

The development and testing of the imaging sensor based prototype has been finalized. The verification experiments employed silk-inoculated maize kernels that mimic natural field aflatoxin contamination. The cleaned samples had a mean aflatoxin equal to 1.2 ppb (parts-per-billion). As a comparison, the sorted contaminated maize kernels had a mean aflatoxin of 62 ppb. The image sensor based device would be suitable for use in a grain inspection facility, aggregation or “buying point” or grain mill in developed as well as developing countries.

For the goggle prototype, the project team created a small UVLED (365 nm) array that fits in a goggle enclosure. The UVLED array is powered by a rechargeable battery pack. A single layer of maize kernels can be loaded into a sample tray. The sample tray with approximately 33-gram maize kernel capacity can be inserted into the goggle enclosure for sample inspection (Figure 2). A UV blocking film was used for viewer protection. The goggle prototype was completed in 2017.

AflaGoggles prototype uses a built-in UVLED array powered by a rechargeable battery pack. The goggle can be used to inspect a sample and screen for aflatoxin.

The goggle prototype is still being tested and evaluated. The initial results showed inconsistent detection, therefore, the research and testing will continue for the foreseeable future in order to further improve the detection accuracy.

The goggle prototype employs human vision to detect contaminated kernels under UV. Because this device is not as sensitive as the image sensor based device, the most appropriate use for this device would be as a quick check for mold contamination and suitability for human consumption, mainly in developing countries.

Technologies for Further Scaling and Adoption

The prototype inspection device with UV fluorescence imaging has generated encouraging results in sorting out contaminated maize kernels and greatly reducing the overall aflatoxin contamination levels in the cleaned maize stock. The recommendation is to use this approach as a low-cost method for maize cleaning in developing countries. The plan is to scale up the technology with an improved processing capacity. Mississippi State University (MSU) has signed a collaborative agreement with an industry partner, Secure Food Solutions (SFS) from Memphis, TN for commercializing the rapid aflatoxin detection technology. A three-way Cooperative Research and Development Agreement (CRADA) including Mississippi State University, USDA, and SFS was also established for continuing this research and development effort. The current joint effort is to work on an approach to scale up the inspection capacity and to refine the procedure for testing. Initial funding has been secured for the new development in 2018. In view of this progress the project team will, with the knowledge and experience acquired through the PMIL project, move much closer to real-world applications.

Future Research Needs and Priorities

An important need is to extend the current work on maize to contamination detection in peanuts. For spectral characterization of aflatoxin contaminated peanuts, the project team has worked on fluorescence hyperspectral imaging and near infrared spectroscopy (NIRS) on fungal inoculated as well as aflatoxin spiked peanut kernels. NIRS on spiked peanuts had a detection accuracy of above 85%. The fluorescence hyperspectral imaging of inoculated peanuts had better results in blanched kernels than raw redskin peanuts. Work in the near future aims to apply the UV imaging prototype to sorting blanched peanuts. Spectral characterization of contaminated peanuts will also be continued. Several research publications are in progress.

Since the AflaGoggles could provide a low-cost method for the developing countries, research will continue to improve and test the AflaGoggles prototype with maize. The goal is to produce more consistent results in sorting the contaminated kernels.

Lessons Learned and Changes Made in Project Objectives

We have learned that human eyes have very low sensitivity in the desired spectral range for aflatoxin contamination detection. In the initial experiment, participants attempted to determine potentially aflatoxin-contaminated maize kernels under different lighting conditions. This initial work did not produce acceptable results. Thus, the later part of the research was altered to focus on UV fluorescence imaging. The tablet based app developed in the project had positive results in sorting the contaminated maize. This change enabled the project to produce a portable aflatoxin contamination detection device, which is more expensive than the original a goggles approach. Also due to this change, the initially planned field testing in the focus country, was not carried out. Instead, several domestic tests were implemented with field inoculations in 2015 and 2016. With the success of the above work, the project team used the last period of the project to finalize an AflaGoggles prototype with considerably lower cost. Similar to the assessment from the early stage of the project, the AflaGoggles did not yield consistent results. However, this development is still important as it helps to set up a foundation to further explore the potential for rapid and low-cost aflatoxin contamination detection device for the developing countries.

Technically, when addressing the need of high performance UVLED for maize sample fluorescence excitation, it was noted that the prototype uses a high power UVLED array that needs constant cooling which shortens operation time. To correct this, one option is to use battery powered custom-made UVLED array with low heat dissipation. This will also improve the portability of the device. The later part was integrated in the prototype of the AflaGoggles. The main scientific challenge is to understand the interaction between fungal infection and aflatoxin production in both toxigenic and atoxigenic fungal strains.

Project B2. Development and Validation of Methods for Detection of Mycotoxins Exposure in Dried Spotted Blood Samples

The goal of this project was to establish and validate methods for measuring major mycotoxin biomarkers, especially for aflatoxin-lysine adduct, in human dried blood spot (DBS) samples for supporting urgent needs of nutrition impact and intervention studies conducted in Asia and Africa countries by the Feed the Future PMIL and Nutrition Innovation Laboratory (NIL). The method has been validated and applied to assess susceptibility factors in determination of human aflatoxicosis, to evaluate the linkage between aflatoxin exposure and human nutrition deficiency and growth retardation and developmental inhibition in children.

Achievements

The first objective was to develop a method for measurement of aflatoxin B_1 (AFB)-Lysine adduct in dried blood spot (DBS) samples. We evaluated various commercially available DBS cards for their accuracy to hold different quantities of whole blood, developed different washing strategies for efficiency to elute bound blood components, especially for elution of total protein and albumin spotted on DBS card, and established methods to measure concentrations of total proteins and albumin in diluted micro-volume washing solutions. The conditions of enzyme digestion to release AFB-bound lysine adduct from the protein were optimized, a method for concentration and purification of AFB-lysine adduct in digests developed, and analytical chemistry parameters, such as accuracy, precision, sensitivity (limit of detection), reproducibility, and recovery for the method were determined. We also validated the method using whole blood of rats and obtained linear correlation for the method.

The next objective was to validate the DBS method for detection of aflatoxin B_1-Lysine (AFB-Lys) adduct in animals and humans. The analytical protocol and correlation between AFB_1 exposure and levels of AFB-Lys adduct in DBS samples in animals and human samples were evaluated. Our results showed that AFB-Lys adduct levels in DBS cards and serum samples from animals and from spiked human samples were comparable and the DBS technique and analytical protocol was then ready to move to a field study aimed to assess AFB_1 exposure in infant and children populations.

The developed protocol was further tested using small scale human samples compared with the matched serum samples from the same study participant. DBS cards prepared from human whole blood were spiked with known levels of AFB-Lys adduct and human serum samples from Kenya and Uganda were used for the validation study. Further, DBS samples (n=172) collected from a high-risk area of children growth stunting in Nepal were used to validate the methods for measurement of AFB-Lys adducts. Each of these DBS samples were processed and analyzed using previously developed laboratory protocols. The results of DBS samples were further compared with those of corresponding serum samples collected at the same time from same study participant. The overall Pearson's correlation coefficient was 0.69 ($p = 0.0006$) between DBS and serum samples. The Bland-Altman plot analysis also showed a good agreement with over 95% samples within the mean difference ±1.96 standard deviation. Results of this study suggested that our previously developed HPLC-florescence method is valid in detecting the AFB-Lys adducts in the field collected DBS samples, and the method is now accepted for application in large scale epidemiological studies in Nepal supported by the Feed the Future Innovation Lab for Nutrition.

Finally, we focused on the application of the method for detection of AFB-Lys adducts in a large number of DBS samples collected from an on-going cohort study in a high-risk area of childhood stunting. The AflaCohort Study, conducted by Nutrition Innovation Lab runs from 2015 to 2018 and a total of 1,675 pregnant women ages 16-49 were recruited from 17 villages in the Banke district, Nepal. A total number of 670 DBS samples collected in 3 batches were processed for analysis of AFB-Lys adduct. A statistically significant difference ($P < 0.01$) was found among these 3 batches' samples collected from different times of the year.

The project investigators also provided critical support for PMIL Virginia Tech project (Project B3) which made comparisons among different available extraction methods for measurement of peanut products at different labs in target countries. We also provided validation and technical support for development of the Mobile Assay mReader for detection of aflatoxins in peanut and peanut products. Further, we analyzed AFB-Lys adduct in blood samples from participants (n=45) of the Malawi nutrition intervention study conducted by PMIL (Project B4). We found high and variable levels of aflatoxin exposure among the sample as demonstrated by the detection rate of 97.8% (44/45) and median AFB-Lys adduct level of 5.19 (range: 0.51-568.87) pg/mg albumin. Moreover, we analyzed AFB-lysine adduct for more than 3,500 serum samples collected from East Timor, Kenya, and Uganda human population studies conducted by collaborators from the Nutrition Innovation Lab through Tufts University and International Food Policy Research Institute.

Technologies for Further Scaling and Adoption

The HPLC-florescence method for analysis aflatoxin biomarker in DBS samples developed by this project will be transferred to the collaborators in the PMIL and Nutrition Innovation Lab targeted countries. The method is ready for application in large scale epidemiological and nutritional studies for investigation of aflatoxin exposure in infants and children and outcomes of their growth and development, and will be extended to field studies conducted by USAID targeted Asia and Africa countries.

The Mobile Assay mReader, a rapid screening method for measurement of aflatoxins in peanuts and peanut products validated in our lab, can be extended for global collaborators.

Future Research Needs and Priorities

The validation of this new method of analysis should reduce logistical complications and cost of determining levels of aflatoxin exposure in human blood. This will make large scale epidemiological studies evaluating the impact of aflatoxin exposure on nutrition and human development easier and hopefully clarify remaining questions of the extent of this public health concern. It may also be applied in targeting and evaluation of the human impact of aflatoxin mitigation strategies.

Lessons Learned and Changes Made in Project Objectives

We were requested by the USAID Egypt mission to help develop the capacity of the Egyptian Ministry of Health to locally analyze AFB-Lys in serum samples due to restrictions on shipping the samples to a foreign lab. Our experience proved that the complexity and expense of establishing and maintaining a lab with this capacity for limited numbers of tests supports the recommendation to seek exceptions to this export ban for research purposes. It is possible to train lab technicians in our US lab and then to establish a lab capable of these analyses, however it will require a minimum of several months and a substantial budget.

Project B3. Aflatoxin in Peanut and Peanut Products: Comparative Study on Analytical Methods for Detection of Aflatoxin

A primary limitation of aflatoxin determination in peanuts is the lack of generally accepted and standardized methods for testing laboratories to quantify the level of contamination feasibly. Even among the PMIL program collaborators, different analytical methods are being used across labs, which can make the comparison of results difficult. The project implemented a systematic comparative study to evaluate and report on existing and emerging analytical methods for aflatoxin determination in peanuts and peanut products. In a blind test, a variety of peanut products, which may present different challenges of background matrix for extraction, were naturally and artificially contaminated with aflatoxin to test the available analytical methods within the collaborating institutions and analytical laboratories. Results from the project were helpful to document the existing quantitative methods being used at the various labs, the advantages and disadvantages of each method, and which methods are most appropriate for various conditions.

Achievements

The overall objective of the study was to compare existing analytical methods [Enzyme-Linked Immunosorbent Assay (ELISA), Fluorometric Immuno Affinity Column (IAC), High Performance Liquid Chromatography, Lateral Flow Devices (LFD) with proprietary reader, and LFD with tablet-based m Reader] on the basis of ease of use (time required for sample prep, and interpretation), cost per sample, sensitivity, and repeatability to detect and monitor aflatoxin in peanut products. Using the results, we were able to suggest the implementation of the mReader across projects as a viable, low-cost option.

A survey, namely "Capability and Capacity Questionnaire of Mycotoxin Testing Facilities", was prepared to collect information related with the present analytical methods applied to determine the aflatoxin level in peanuts used in cooperating institutions of PMIL program. The survey was disseminated via the PMIL webpage and through individual communications. Eight different labs from various countries (Uganda, Malawi, Ghana, India, and USA) were selected and samples of peanut products (RUTF, peanut paste, peanut flour and peanut oil) spiked with known amounts of aflatoxin (either with aflatoxin B1 or Aflatoxin B + G mixture) and/or infected with *Aspergillus* spp. were distributed to conduct a "blind test".

Analysis methods tested were HPLC, AflaTest Fluorometer by VICAM, FluoroQuant Afla by RomerLabs, RevealQ+ LFD by Neogen, Homemade ELISA, ELISA by RomerLabs and mReader by Mobile Assay. While the results did vary across labs, most labs did report measurements in the same range of the actual sample. The results did confirm that the mReader was as accurate as the HPLC and VICAM methods, both of which are considered valid methods.

Technologies for Further Scaling and Adoption

The study supported the use of the MobileAssay mReader and Neogen test strips for routine aflatoxin measurements.

Future Research Needs and Priorities

As new methods are made available, additional evaluations will be needed.

Lessons Learned and Changes Made in Project Objectives

Survey results indicate that the most popular method in our sample is HPLC followed by fluorometric methods (using immunoaffinity columns), ELISA and lateral flow devices. Even though HPLC is the most common method, it has the disadvantage of needing cleanup techniques to improve the separating power of chromatography, which can be improved using immunoaffinity columns or solid phase extraction methods. The majority of the survey participants using the HPLC for aflatoxin analysis prefer immunoaffinity column cleanup procedure prior to chromatographic analysis. Fluorescence detection is a very good alternative in terms of high sensitivity, which is why it was the second method of choice for aflatoxin analysis as it can be combined with HPLC. Both fluorometric methods like AflaTest Fluorometer by VICAM or FluoroQuant Afla by RomerLabs and HPLC require well-equipped laboratories and trained personnel. The time of analysis was reported to be 60+ minutes for HPLC and 30-60 minutes for fluorometric methods using immunoaffinity columns. Both techniques are also expensive, with an average cost of the analysis of $65 with a highest value of $100 per sample using HPLC and average cost of fluorometric methods of $35 with a highest value of $40-$70.

The ELISA test has an advantage of not requiring any cleanup step and offering easier operation, and also it is portable for use in the field for the detection of mycotoxins in foods and feeds applications. As a disadvantage, it is dependent on the individual matrices of interest. Owing to the posible interaction of antibodies to chemically similar substances in food matrix to aflatoxin, false posive results may be observed. However, compared to the other techniques the average cost of analysis using ELISA was reported as $25 with a maximum value of $45 and time for the analysis is 30-60 minutes depending on the number of the samples. When rapid screening is needed, ELISA offers the shortest time for a large number of sample analysis. The survey done within PMIL partners showed that the Lateral Flow Devices (LFD) is the fourth most common method of choice. LFD devices are commonly used for semi-quantitative/threshold analysis, though accurate quantitative analysis is possible using either a propriety strip reader or the tablet based mReader. One major advantage of LFD is that the test can be used in field because the sample preparation is fairly simple, requiring no complex equipment and some brands of strips do not require refrigeration. This is important in developing countries where storage and testing equipment is limited. Field analysis also eliminates some potential of sample contamination and opens opportunities for early segregation of contaminated crops to prevent aggregation of good and bad lots, and possible to offer incentives to individuals with uncontaminated crops. Large batches of samples can be interpreted in short time (10-20 minutes) and the shelf life of strips is longer than enzyme immunoassays. The cost of the analysis is lower than other methods compared ($18-$36). These data suggest that the method is quite accurate, however training of technicians remains a critical challenge for accurate results. For example, samples above the limit of detection for the LFD require serial dilutions, but may be reported as simply the maximum possible result even though it may be much higher.

Project B4. Randomized Controlled Trial of the Impact of Treating Moderately Malnourished Women in Pregnancy

The objective of this project was to determine the benefits of treating moderately malnourished pregnant women with a peanut butter-based nutritional supplement. The trial was a randomized, investigator-blinded controlled clinical effectiveness trial in pregnant women with moderate malnutrition, with and without HIV-infection, in southern Malawi.

The trial used three different nutritional supplements for comparison: (1) a Ready-to-Use Supplementary Food (RUSF) formulated to deliver about 200% of the RDA of most micronutrients in pregnancy (RUSF-P); (2) fortified corn soy blend (also known as CSB+ or super-cereal) with a multiple micronutrient tablet chosen to deliver about 200% of the RDA of most micronutrients (CSB-P); or (3) the standard of care which is a fortified corn soy blend, vegetable oil and sugar with supplementary iron and folic acid tablets (CSB), delivering between 0-350% of the RDA. The primary outcomes for this study are both maternal; recovery and Mid-Upper Arm Circumference (MUAC) change; as well as infant outcomes in mean birth weight, mean birth length, and percentage of premature delivery.

The aim of the study was to provide significant evidence that using a peanut-based supplementary food will reduce maternal mortality and improve infant growth and development. This would provide national and international agencies with evidence to recommend and promote the use of peanut-based products for maternal health and to procure these products for use in their nutrition programs.

Achievements

During the study period, 2284 pregnant women with MUAC ≤23 cm were screened for the study participation. 456 women were excluded from the study and 1828 were randomized into treatment groups. There were 1467 live singleton births, 18 live twin pairs and one set of triplets. 94% of infants were measured within 24 hours and 98% were within 48 hours of birth. All follow up, data entry and data analysis has been completed for the study. The results, overall, were remarkably similar when moderately malnourished pregnant women received a supplemental feeding. 75% of all participants had low weekly weight gain, defined as <454 g/wk. Mothers in the RUSF groups had the highest mean gestational weight gain (3.4 kg, 3.0 kg, 3.2 kg in RUSF, CSB+ with UNIMMAP and CSB+ with IFA respectively, $P = 0.03$). There were no differences across treatment groups in any infant outcomes except for the rate of low birth weight, defined as weighing ≤ 2.5 kg or weight-for-age z-score (WAZ) with the CSB+ with IFA group having the lowest rate (19%, 23%, and 14%, RUSF, CSB+ with UNIMMAP and CSB+ with IFA, respectively $P = 0.12$). Using regression modeling, the duration of treatment was shown to be a determinant of infant length, suggesting that food supplementation is more effective when started earlier in pregnancy and given longer. The model showed that the odds of an infant being stunted at birth decreased by 3.9% with each additional week the woman received treatment. Although linear growth was generally compromised with maternal under-nutrition, head circumference was spared.

A peer-reviewed article titled “Trial of ready-to-use supplemental food and corn-soy blend in pregnant Malawian women with moderate malnutrition: a randomized controlled clinical trial” was published on August 9, 2017 in the American Society for Nutrition. Additionally, a paper titled “Adolescent pregnancy and nutrition: a subgroup analysis from the Mamachiponde study in Malawi" is pending publication in the Annals of the New York Academy of Sciences issue: Adolescent Women's Nutritional status.

Technologies for Further Scaling and Adoption

None.

Future Research Needs and Priorities

The modest benefits seen from food and micronutrient supplementation alone were not enough to affect better growth in utero, especially during this small treatment window. This puts a renewed interest in multiple areas, such as how diet, inflammation, gut health, and epigenetics, affect growth in utero. Research on some of these areas has been conducted on pregnant women, mostly malaria controls and other interventions against infectious disease. These studies have helped modestly reduce the risk of prematurity, fetal growth stunting, and small-for-gestational-age birth. We are currently in the process of conducting a study that combines both diet and interventions against malaria and common infect diseases in a rural area in southern Sierra Leone. We hope that our future combined study will show more than a modest result.

Lessons Learned and Changes Made in Project Objectives

The study had experienced a larger percentage of women than originally anticipated in "loss to follow up" group, mainly due to delivering before they could receive a full 14 days of treatment. The treatment type did not affect hemoglobin concentrations. On average, women received a total of 5.0 rations of the food intervention over a period of 11.4 weeks from enrollment until delivery. Average MUAC at delivery was 22.2 cm and did not differ by treatment group ($P = 0.11$). The RUSF group had the greatest number of participants (35%) who attained MUAC >23.0 cm prior to delivery, followed by CSB+ with IFA (33%) and CSB+ with UNIMMAP (30%), but there were no differences between groups (P=0.14). Anemia was reduced after 10 weeks of treatment in all groups, from an average prevalence of 71% to 56%.

The study was limited in that no true control group was included, all women received some supplementary feeding in order to meet national guidelines in Malawi; however, these guidelines are rarely implemented. The data regarding gestational age could have been strengthened if ultrasound technology had been employed to assess the subjects.

C. Peanut Value Chain Interventions

Project C1. Production to Consumption – Technologies to Improve Peanut Production, Processing and Utilization in Haiti

The overall goal of this project was to address and mitigate key constraints to peanut production and utilization in Haiti. Peanuts have been and continue to be an important part of Haitian diet and culture as well as providing an important source of cash income. To combat malnutrition in the country, certain NGOs have established facilities to produce peanut-based Ready-to-Use Therapeutic Food or RUTF. To date, however, there has been limited utilization of locally grown peanut due to issues with low productivity linked to high costs and aflatoxin contamination.

In this project, we implemented a comprehensive production, processing and utilization strategy for peanuts in Haiti. All phases of peanut production were evaluated, including varieties specific to the region and market influences. We instituted a seed-increase program and developed facilities to maintain genetic resources through curation of important peanut germplasm. Capacity building through the introduction of labor saving devices and harvesting equipment and procedures continues, along with evaluating the infrastructure to improve peanut handling, drying and long-term storage. After evaluating the best management practices and strategies, we have taken them to the grower level at several communities in the region, particularly through the depot network partnership with the Acceso Peanut Enterprise Corporation. We provided training and infrastructure support to realize these improvements and ensure long-term capacity building. Aflatoxin and the role of women in the peanut value chain was measured/surveyed throughout the duration and in all phases of the project. We also established aflatoxin-testing facilities and re-trained Haitians in how to measure and the importance of avoiding aflatoxin in their diet. Another important aspect was the creation of alternative products/markets for high aflatoxin contaminated peanuts.

Achievements

- Conducted trials on fertility, seed spacing, disease management with fungicides and variety evaluations at two locations (Quartier Morin, North Haiti and Coup Gorge, Central) – this totaled 30 trials from 2014-2017. These trials were in conjunction with the PhD dissertation of Abraham Fulmer at UGA. We determined the optimum planting spacing, disease management strategy, fertility requirements for both runner and Valencia peanuts. We also determined the best varieties and traits for future varieties to assist in the efforts of in-country breeders.
- Developed successful intern program with four local universities (Université Roi Henri Christophe, Université Chrétienne du Nord d'Haiti, Université de l'Etat- Campus Roi Henri Christophe, and Université Solidarite d'Haiti) for final year agronomy students to participate in research plots, with 34 successful student projects completed as part of the trials listed above.
- Conducted variety trials in conjunction with Barry Tillman (UF) and Raphael Colbert (Quisqueya University). Variety trials also included premier ICRISAT lines and lines from PMIL collaborators David Okello, NARS groundnut breeder in Uganda, and Dr. Naveen Puppala at New Mexico State University, as well as other public and privately bred US varieties.
- Conducted additional trials at Quartier Morin on various formulations and rates of phosphorus and complete fertilizers, micronutrient foliar fertilizer, fulvic acid and biochar amendments, as well as liquid bradyrizobium inoculant. These were shown to be only marginally beneficial, although additional research on phosphorus and nitrogen on high pH soils is warranted.
- Performed trials with Premier Steppe Ferme, Inc. and iF Foundation – variety tests and scale-up of semi-mechanized, large scale seed systems. This included equipment technology transfer and production assistance, such as use of mechanical planter, two-row digger/shaker/inverter and PTO thresher. This program is currently working well, with peanut seed produced being sold to Acceso for their credit program to over 2000 farmers.
- Provided training and farmer field demonstrations in North, Northeast and Central Plateau departments.
- Provided technical training, materials and support to Acceso Peanut Enterprise Corp. This included production guides, field visits, aflatoxin training for depot managers, technical expertise in planting, harvesting, storage and aflatoxin detection.
- Completed two large producer surveys, including a baseline and impact evaluation, in collaboration with Acceso, producing two publications near completion.
- Completed an economic analysis of fungicide inputs derived from Fulmer's multiyear, multi-location trials. A US graduate student at UGA completed this work for a MS thesis at no cost to PMIL.

- Provided guidance and expertise to MFK agronomists for their ongoing extension program funded outside of PMIL.
- Continued support of the aflatoxin detection facility at iF Foundation – additional training of staff; established a Research/Teaching mycotoxin lab at Faculté d'Agronomie et de Médecine Vétérinaire (FAMV), Université d'État d'Haïti in Bon Repos.
- Conducted small scale testing of peanut by-products (high aflatoxin contamination) for alternative usage. This include charcoal production, oil extraction with ethanol wash, and feeding trials on several animals – chicken for meat and egg, beef and dairy.
- Completed a peer reviewed research review of all field research completed in Haiti under PMIL and PCRSP.

Technologies for Further Scaling and Adoption

- Successful adoption of used US two-row equipment at Premier Steppe Ferme, as well as Brazilian-made Colombo PTO thresher. Such medium scale equipment is of interest for other commercial scale farmers in Africa, including seed producers.
- The accumulated data of the multi-location trials will reshape the technology package recommendations offered by Acceso and others. The primary take-aways include the positive impact of increased planting density, particularly with the Haitian Valencia variety, and cost effectiveness of limited, but well-timed fungicide applications.
- While the trials supported the continued focus on the Haitian Valencia variety, improved lines from ICRISAT and Dr. Tillman and Dr. Puppala have been multiplied and trials will continue.
- The research using an oil press for contaminated peanuts and ethanol feed wash techniques has been taken up by the IDRC-funded AFLAH project managed by Université Laval and Université Quisqueya for continued refinement.

Future Research Needs and Priorities

- The potential for impact through improved varieties remains high despite not identifying varieties that consistently out-yield the locally adapted Haitian Valencia. A breeding program to introduce improved traits into this variety, such as disease resistance, drought tolerance, high oleic acid and higher yield, should be pursued, while continuing to evaluate germplasm from a wide source of PMIL collaborators. Haiti's high pH soil conditions and high rust pressure may require unique breeding considerations. The integration of the value chain and breeding initiatives was late forming in the project, but should be enhanced and continued.
- Attempts to ameliorate soil deficiencies through fertilizer showed very limited and likely uneconomic return on investment. New strategies, such as more intensive rotations to increase soil organic matter, doubled legume (pigeon pea) or cover cropping, should be evaluated as a means to address the high pH soil limitations.
- Research plot data needs to be confirmed at scale and on farm and be thoroughly evaluated for return on investment. Adoption of fungicide may increase yields, but economic returns in low yielding situations may be difficult.
- The baseline survey showed willingness for farmers to consider index insurance, which may improve investments in productive input investments. This should be further investigated.
- Initial collaboration with Premier Steppe Ferme yielded advances in scaled production, but further refinement for sustainability and improved seed quality is needed.

Lessons Learned and Changes Made in Project Objectives

- The farmer surveys corroborated extensive field experience that average yields are much lower than the FAO reported 860kg/ha and are more likely 250-300kg/ha, which puts productivity in Haiti among the lowest in the world. Field trial data, especially under irrigation at MFK, regularly reported yields of over 4000kg/ha with runner and 3000kg/ha with Valencia varieties. This >10x yield gap shows the potential for what can be achieved on-farm with continued support.
- With the establishment of Acceso in 2014, the project shifted some focus from extension to more research and training of trainers in support of the technical package to be offered in their credit program. This allowed for much greater and more sustainable interaction with thousands of farmers in multiple regions than was previously possible.
- Significant technical support, but very limited financial support, was offered to Premier Steppe Ferme who decided to invest in peanut as a primary focus crop due to the markets and technical support of PMIL. This produced a great resource for seed multiplication and future scaled research.
- Once the MFK research facilities were fully operational and adequate technical support was available to students, the internship program yielded fantastic results with quality data and much greater capacity development.

Project C2. Applied Research and Technology Transfer to Minimize Aflatoxin Contamination and Increase Production, Quality and Marketing of Peanut in Ghana

A wide range of abiotic and biotic stresses negatively impact peanut production in the field and generally contributes to the reduced quality of marketed peanut in Ghana and West Africa. Aflatoxin contamination can occur and increase at all steps of the peanut supply chain including production in the field, storage in fields and villages, and during processing. Interventions at each step of the supply chain can minimize aflatoxin contamination. Improved production in the field including pest- and disease-resistant cultivars, adequate soil fertility and plant nutrition, and synchronization of peanut pod growth phase with adequate soil moisture can increase peanut yield and quality and minimize aflatoxin contamination. Adequate and timely drying of farmer stock peanut minimizes additional production of aflatoxin during storage in villages prior to marketing. Effective processing of farmer stock and shelled stock peanut can also reduce aflatoxin prior to purchase and consumption. Determining current practices by farmers, conducting research to mitigate aflatoxin and improve peanut quality, and transferring appropriate technology to farmers are needed to improve productivity, profits, and quality of peanut and to increase safety of peanut products consumed by humans and livestock.

The primary platform used to research aflatoxin contamination of peanut in the supply chain in Ghana took place in nine villages in northern and central Ghana. Interventions at each step of the supply chain were implemented and aflatoxin contamination was determined. Research was conducted at two CSIR institutes, the Savanna Agricultural Research Institute (SARI) and the Crops Research Institute (CRI), to develop appropriate production and pest and disease management strategies, and to evaluate new germplasm suitable for the regions. Results from efforts at villages and research stations were presented to farmers using the Farmer Field School approach and appropriate posters, bulletins, and manuals. Graduate student training and research was closely linked to activities in villages and research stations.

Results from the project will provide farmers in Ghana with information on documented interventions that reduce aflatoxin contamination of peanut throughout the supply chain. Improved productivity and quality of peanut coupled with acceptable levels of aflatoxin in peanut products will improve access to local, regional, national and international markets leading to enhanced economic viability of farmers and their communities.

Achievements

Objective 1. Evaluate the effect of on-farm interventions at production, drying, storage and processing steps on aflatoxin contamination in the peanut

The goal of this objective included comparing farmer practices (FP) and improved practices (IP) in the field (planting dates either in a single season or major vs minor seasons), FP vs IP for drying (ground drying vs drying on tarps), and comparisons of storage using traditional bags (FP) vs hermetically sealed bags (IP) to reduce aflatoxin contamination. Five villages were used (two near CRI-Kumasi, two near SARI-Tamale, and one near SARI-Wa) with approximately 10 farmers in each village to compare FP with IP. Farmers served as replications in the villages. Within each planting date, the FP was compared with an IP program that included applying local "alata" soap for disease/aphid-rosette suppression, applying calcium for pod/kernel development and strength to minimize insect damage, and weeding by hand one additional time. A full complement of data was recorded prior to and at harvest relative to pests in the field, yield, pod and kernel formation, and aflatoxin contamination. Each intervention was compared for economic impact, and pod/kernel quality evaluated after storage and aflatoxin contamination quantified after each step in the process (field, drying, and storing).

- Results from two villages in central Ghana compared the effectiveness of FP and IP. Peanut yield and estimated economic returns were higher with the IP compared to the FP.
- Minor, but significant differences in aflatoxin concentration in peanut farmer stock were noted when sampling occurred immediately after harvest and prior to drying (1.0 versus 0.5 µg/kg, $p = 0.0015$ at Drobonso and 0.3 versus 0.5 µg/kg, $p = 0.0290$ at Ejura).
- In both villages, aflatoxin levels increased during drying. At Drobonso, benefits of effective drying on plastic tarpaulins (29-80 µg/kg aflatoxin) became apparent compared with ground drying (153-226 µg/kg) regardless of the level of aflatoxin coming out of the field at harvest. These respective drying practices resulted in 8-31 µg/kg and 68-93 µg/kg at Ejura.
- As these peanuts continued through the supply chain, the concentration following relatively low input in the field, drying on the ground, and storage in readily available poly sacks with limited protection resulted in an average aflatoxin concentration of 1407 µg/kg at Drobonso.
- Use of IP at all stages resulted in the lowest aflatoxin concentration (53 µg/kg) at this location. Adopting a single IP or two of the three possible IPs resulted in aflatoxin concentrations between 100 and 548 µg/kg. At Ejura, using FP at all steps resulted in aflatoxin concentration of 766 µg/kg versus only 15 µg/kg when IP were included in the field and during drying and storage.

These results from two villages in central Ghana show how each step in the value chain impacts the concentration of aflatoxin in the final product. Peanut after storage will be consumed directly by individuals in the household or will enter the market in some form. Economic return captured at harvest could change during storage, depending on quality and seasonal price dynamics, especially if buyers consider aflatoxin contamination in their decision-making process. Whether farmers adopt improved practices to reduce aflatoxin may be determined by the market valuation of low-aflatoxin peanut and resulting better prices (see Project C3). While productivity interventions showed the least impact on aflatoxin contamination, the increase in yield and profitability may be required for farmers to investment in drying and storing technologies that have greater impact on quality.

Objective 2. Evaluate pre- and post-harvest technologies to reduce aflatoxin contamination *on-station* at SARI and CRI

Trials were conducted at CRI-Kumasi, SARI-Tamale, and SARI-Wa associated with various scientific disciplines. Some of these trials were associated with graduate student thesis projects outlined in Objective 7. Summaries of key findings from several projects follow.

WEED CONTROL: Most peanut farmers in Ghana cultivate small farm sizes because most rely mainly on manual weed control. Thus, research was conducted to determine the interactive effect of chemical or manual weed control and fungicide application on weed suppression and peanut growth, yield and quality. At six weeks after planting, pre-emergent application of S-Metolachlor combined with hand-weeding reduced weed density by 88%; pre- and post-emergent application by 89%; and hand-weeding only by 30% relative to the non-weeded control. The three most locally important weeds of peanut, Benghal dayflower (*Commelina benghalensis*), purple nutsedge (*Cyperus rotundus*) and wild poinsettia (*Euphorbia heterophylla*) were well controlled with Imazethapyr, while S-Metolachlor was more effective on Benghal dayflower and grasses. Yield did not differ significantly among treatments. However, economic analysis proved that including chemical weed control was more profitable than hand-weeding alone. Two hand-weedings cost GH₵ 1,668.2/ha (US$ 417) and required 66.6 person-days/ha. Herbicides, in combination with hand weeding, reduced cost by 53-60% and time to average of 25 person-days/ha compared to manual alone, while pre- and post-emergent herbicides used together reduced cost by 94% and required 1.3 person-days/ha for weed control. Aflatoxin levels of fresh and dried seeds were very low (< 2.0 PPB). Fungicide treatment did not interact with weed-control practices with respect to peanut growth and yield, most likely because environmental conditions during 2015 minor season was relatively dry and did not favor disease development. The experiment was repeated in the major of 2016 at different locations with a local check.

PROCESSED GROUNDNUT QUALITY: Peanut paste is a delicacy in Ghana, and this study aimed to assess peanut paste quality in northern Ghana, where quality is inconsistent. Twenty-four peanut paste samples were acquired from six major markets, while a control sample was prepared in the Food Science and Technology Laboratory of KNUST using the Nkate-sari variety of peanut. A survey was conducted using structured questionnaires to collect processor's methods, while samples were tested for aflatoxin and microbial load. There was no sorting, grading or blanching during processing, and 75% of producers used untreated stream water during processing.

Ninety-six percent of traders acquired raw peanuts from the market already de-shelled.

Moisture, crude protein and carbohydrate content of the samples ranged from 5.05 ± 0.07 to 6.45 ± 0.21, 23.67±0.05 to 31.56 ±0.78 and 19.44 ±1.19 to 27.65 ±0.96 respectively. Statistical analysis showed no significant difference ($p>0.05$) between ash, carbohydrate and protein content. Aflatoxin analysis of the Tamale central, Bolga central, Wa Gonomuni, Tamale Aboabu and Wa central market samples showed concentrations of 2.89 ppb, 8.6 ppb, 55.39 ppb, 103.44 ppb and 126.55 ppb respectively. Total aerobic count ranged from 2.5×10^3 CFU/g to 9.9×10^3 CFU/g. Coliform count were below the acceptable limit of 10 cfu/g. Fungal enumeration was less than 101 CFU/g in all samples, except for Navrongo central market samples. *Aspergillus parasiticus* was isolated in Wa gonomuni, Wa central market and Tamale Aboabu market samples respectively. *Blastomyces dermatitidis* was found in Bolga central market samples. Even though some samples had high nutrient composition, contamination levels were significant due to poor production practices.

SOLAR DRYER: A solar dryer was constructed and tested to show that the technology can be used effectively for improving peanut safety and preserving peanut quality in Ghana. An indirect, passive, wooden dryer, with a galvanized steel panel (4.5 m^2) and four wire mesh shelves (2.62 m^2 each), was built in Kumasi, adapted from a previous model constructed at UGA in Georgia, and evaluated for its capacity to dry freshly-harvested in-shell peanuts on a single layer (8.5 Kg) and then in four layers (4x18 Kg). Equal amounts of peanuts, dried simultaneously on a concrete floor under the open sun, served as comparisons.

The moisture content of solar dried peanuts decreased from 35.85% to 5.25% and 32% to 4.25% in the single-layer and four-layer drying, respectively, over four days. Faster drying rates were observed when peanuts had relatively higher moisture contents with R^2 values ranging from 0.72 to 0.95. The average daily solar radiation ranged from 360 to 592.99 W/m^2 and daily energies generated were from 42.24 to 69.16 MJ. The drying efficiency ranged from 1.5% to 6.47% in the single-layer drying and 23.07% to 24.93% in the four-layer drying, whereas the thermal efficiency was 3.15% to 21.60% in the single-layer drying and 3.08% to 24.93% in the four-layer drying.

Peanuts from the solar dryer had lower free fatty acid and peroxide values (indicators of rancidity) and higher germination rates compared to peanuts dried in the open sun, suggesting a potentially valuable quality improvement, likely from the reduced variability of high daytime temperatures.

COMPOSTING: Results of laboratory-scale trials revealed that composting had the potential to be employed to decontaminate aflatoxin-containing agricultural waste in developing countries, where aflatoxin-contaminated peanut waste is often used as mulching material or a soil amendment, which introduces aflatoxins and aflatoxin-producing mold into subsequent farming seasons. Composting highly-contaminated peanut meal at 40°C for six weeks caused levels of aflatoxin B1, B2, G1 and G to drop from 154.9 to 72.2µg/kg, from 17.6 to 7.4µg/kg, from 6.9 to 1.2µg/kg, and from 2.1 to 0.0µg/kg, respectively. *Aspergillus flavus* and *A. parasiticus* counts and total mold counts decreased from 103-105 to <10 CFU/g. Composting time and the type of starters used in the research significantly influenced aflatoxin content, while the presence of an accelerator did not affect aflatoxin levels. The highest level of toxin decontamination occurred in the first week when compost temperature and ammonia concentration were high. Micronutrient contents of resulting composts were within the accepted range for crop fertilizers, except for calcium. Heavy metal content was below the maximum allowable levels except nickel in one of the samples. Therefore, composting of aflatoxin contaminated agricultural waste appears to be an effective means of reducing risk of accumulation.

Objective 3. Evaluate new peanut germplasm from ICRISAT, USA and African breeders
New varieties and experimental lines were compared on research stations coordinated and implemented cooperatively at CRI-Kumasi, SARI-Tamale and SARI-Wa. These trials involved 20 to 30 entries including local cultivars. Results over three years showed significant difference ($p < 0.05$) among groundnut germplasm for pest reaction and yield. The majority of the groundnut germplasm took five days to emergence. Shitaochi, however, had the least number of days to emergence while Otuhia and Adepa had the longest. Considering days to 50% flowering, the majority of germplasm recorded 27 days, with Otuhia recording 31 days. The range for incidence of rosette was between 2% and 74%. Yenyawoso and Shitaochi recorded the least and highest incidence of rosette, respectively. Also, three lines from ICRISAT (ICGV-03308, ICGV-03315 and ICGV-03398) had greater than 60% incidence of rosette over the other entries. Results showed differences in unfilled pod, pod and kernels damage as well as grain yield as a result of arthropod pest reaction among 23 lines and varieties. Generally, germplasm that showed lower incidence of rosette had higher yield compared to those with higher incidence of rosette. The highest grain yield was recorded from Oboshe (3157kg/ha) while the least were from ICGV-03395.

Objective 4. Disseminate best practices to farmers and other stakeholders
Farmer Field Schools (FFSs) were held at each village at planting, mid-season and harvest to demonstrate improved varieties, pest management and production interventions during the season, and aflatoxin mitigation techniques. A concise guide in English and appropriate local languages was distributed through FFSs, the Ministry of Forestry and Agriculture (MOFA), and the PMIL website. From October 2013 to 2017, groundnut IPM production and aflatoxin mitigation technologies were transferred through FFSs to more than 100 farmers and 10 MOFA extension staff which extended the reach to 1500 farmers and extension staff households at Ejura/Sekyedumase, and Drobonso in the Ashanti region.

Surveys of PMIL Collaborating (PMIL-C) farmers, PMIL Spill-over (PMIL-SO) farmers, and General/Other (GO) control group farmers were conducted in October 2016 (see Objective 1, example in Ejura and Drobonso) to determine how information derived from PMIL interactions was disseminated. In all, 112 farmers were surveyed: 26 PMIL-C farmers, 21 PMIL-SO farmers, and 65 GO farmers. 96% percent of PMIL-C farmers had heard about aflatoxin while only 52% of PMIL-SO farmers and 22% of GO farmers had heard about this issue. Most farmers removed moldy grain (the highest risk source of aflatoxin) prior to consuming or marketing peanut. PMIL-C farmers were using improved technologies or recommendations more than PMIL-SO and GO farmers. Approximately 85% of PMIL-C and PMIL-SO farmers used tarps for drying while only 42% of GO farmers used this technique. Hermetically sealed bags were used by 46%, 5%, and 2% of PMIL-C, PMIL-SO, and GO farmers, respectively, while 4%, 9%, and 14% of these respective groups used poly bags. Fifty-two percent of PMIL-C farmers used fertilizer bags while PMIL-SO and GO farmers used this type of storage bag 86% and 79% of the time, respectively.

Objective 5. Analyze the economics of each aflatoxin reduction intervention
In fall 2015, 600 groundnut producers from 50 villages across five districts in central Ghana were surveyed. Obtaining a clean data set ready for analysis has proven to be a challenge, and continued into spring of 2017. The final dataset was still being analyzed at the close of FY 2017. The main focus of the analysis is the prevalence and awareness of aflatoxin among smallholder farmers. Additional data from KNUST researchers on aflatoxin was also provided by collaborators and will be included in the final analysis. The results of this analysis will be incorporated into Jeremy Jelliffe's PhD dissertation at UCONN and a manuscript will be generated and submitted for publication to a peer-reviewed journal upon completion of this work.

Data received from field-experiment trials of alternative management practices in Northern (SARI) and Central (CRI) regions continued for the 2017 growing season. Processing has been done and final analysis of the data is complete. Manuscripts are being prepared to include the results from the analysis, which will be submitted for publication to a peer-reviewed journal.

Data from Ghana will also be used as possible in comparison with those collected in Malawi, Mozambique and Zambia.

Objective 6. Survey level of aflatoxin contamination in peanuts and peanut products and develop recommendations for reducing aflatoxin contamination in the peanut processing value chain
Traders and processors along the peanut value chain were surveyed to assess current practices in aflatoxin mitigation. A market analysis to assess the extent of aflatoxin contamination in peanuts and peanut-based products in the market will be constructed. Seventy-three percent of the processors had perceptions of the causes of defects in raw peanuts. They identified insect attack and inadequate rains as the highest (27%) causes of defects in peanuts, followed by improper drying (23%).

There were no significant associations between the age and experience of the processors and the perception of the causes of defects of peanuts respectively (p=0.39) and (p=0.49). There were also no significant associations between the processors ethnic background (hometown) and their perception of the causes of defects (p=0.10). Thus, most processors considered that improper drying and insect attack were the major causes of defects in peanuts. Consequently post-harvest handling activities such as drying and storage of peanuts are raw material supply issues that should be addressed in the value chain using standard quality management systems. Data from the survey showed that 40% of the respondents thought there were no food safety issues associated with the consumption of defective peanuts while 33% associated the consumption of defective peanuts with stomach pains among other health issues.

Objective 7. Includes development of human and institutional capacity to conduct research in peanut in Ghana.
To date, seven students completed coursework and thesis/dissertation for a graduate degree, two in doctoral programs. The students studied at University of Ghana or KNUST in Ghana, UGA or Virginia Tech in the US.

Technologies for Further Scaling and Adoption

- The recommended improved farmer practices (soap for insect control, calcium inputs through oyster shells or commercial legume fertilizer) proved to be economically viable and should be promoted throughout the peanut growing regions.
- Improved post-harvest practice of tarp drying and hermetic bags also appears to successfully reduce aflatoxin contamination and should be promoted as well.
- Solar drying technologies, such as those deployed at CRI and surrounding villages, may have difficulties to manage the required volumes in a timely manner, but the improvement in quality should be considered by the breeding program to assure seed quality.
- The findings related to peanut product quality should be shared to improve the hygiene and safety (aflatoxin and microbiological contaminants) in peanut flour, kuli-kuli and peanut butter. Likewise, efforts should be made to identify the risk of using sorted out peanuts and oil cake for products such as kuli-kuli and kebab powder.
- Several improved varieties proved to be higher yielding and more resistant to pests and environmental limitations and should be scaled through a sustainable seed system, such as the village approach demonstrated in this project.

Future Research Needs and Priorities

- While technologies proved to be effective at economically improving yields, adoption strategies and availability of inputs remains a challenge to scaling and should be considered for future research.
- The strategic integration of research and seed production with commercial farming and processing operations in other PMIL countries demonstrated the potential of this approach, however these opportunities remained limited and untapped in Ghana to date.

Lessons Learned and Changes Made in Project Objectives

- Large, complex projects across many disciplines and involving many institutions can be successful and offer unique research opportunities, such as the “two by two by two” factorial aflatoxin value chain project. However, they require additional management inputs that may exceed the time limitations of a single US-based PI and have additional costs, such as regular meetings to bring collaborators together.

- Innovative new digital data collection systems, such the World Bank tablet-based survey tool used by the co-PI in the Malawi project or the field trial data system in the Breeding Management Software system would be helpful for timely, accurate data collection across such numerous and geographically separated partners.
- Working with local universities is key to developing long term capacity, but much can also be achieved in two way learning and professional development by incorporating international experts on thesis committees to assure thorough awareness of the specific subject matter, relevance of the research question and design, and to offer opportunities for career development to the students, such as participation in international conferences.
- Having a single facility to analyze aflatoxin samples was initially required due to the limited availability of testing equipment and to reduce potential error between labs. However, this created logistical and cost challenges relating to keeping samples frozen and shipped to the central lab. It also created extensive delays in data analysis that limited timely interpretation of the results. Future efforts should consider lower cost and field based testing, such as the Mobile Assay system introduced in the later years of the project.
- Solar drying presents some challenges for peanuts since high temperatures negatively affect peanut quality for flavor, shelf life and germination, and volumes of the tested technologies were too limited for widespread adoption as currently configured. However, the demand for a "set it and forget it" drying technology that protected the drying crop from rain and livestock was clear. Also, the improvement in germination over sundried peanuts demonstrated the need for controlled drying for breeding programs and seed producers.

Project C3. Producer and Consumer Interventions to Decrease Peanut Mycotoxin Risk in Ghana

The goal of this project was to investigate the relative and combined impact of technological and market aflatoxin mitigation interventions for groundnuts in northern Ghana. The technological intervention facilitated the adoption of simple and low-cost aflatoxin prevention technologies. Essentially, we gave a randomly selected subset of study farmers the materials and information necessary to adopt. We worked with local experts to identify the preventative measures with the best potential to provide long-term and affordable solutions. The market intervention ensured a premium for a different and partially overlapping randomly selected subset of study farmers. To do this, we worked with local groundnut buyers to offer a premium for groundnuts tested by the project that pass a safety criterion. Producers selected to receive the market intervention are made aware of the potential customers for safe groundnuts, and what the standards are to qualify for the price premium.

In Ghana, women constitute over 48% of the agricultural labor force. Furthermore, women are the main purchasers of groundnuts, and then use them to make paste and extract oil. Hence, when designing the questionnaires and intervention we considered gender differences. We built in modules on gender, individual assets and joint asset ownership at baseline. In this way, we have attempted to capture the gender dynamic around reasons why/why not individuals or households adopt control measures.

Achievements

Designed a group training program and trained 1,000 farmers on aflatoxin and aflatoxin prevention
The research team created a training program with local extension agents to teach farmers about aflatoxin, its risks, and how low cost harvest and post-harvest practices can reduce them. This program includes interactive discussions, demonstrations, a short video shown on tablet computers, and a refresher quiz. It lasts roughly one hour.

We used this program to train 750 farmers in group sessions with local extension agents and members of our research team before the 2015 groundnut harvest and an additional 250 farmers after the 2015 groundnut harvest (this was the control group for the first year of the study). The same farmers received one-on-one refresher training in 2016. The trainings were very effective at improving sorting and storage practices.

Lowered aflatoxin levels in treatment arms of our sample by 20-30 percent in the Northern Region.
In 2014-2015, aflatoxin levels were very low across Ghana making it unlikely any interventions would have a detectable impact. The same can be said for 2015-2016 in the Upper East Region. In the Northern Region, where baseline levels were higher in 2015-2016, the free tarp intervention lowered aflatoxin levels by an average of 30 percent for 203 farmers and the market premium lowered aflatoxin levels by an average of 20 percent for 122 farmers. Looking at critical thresholds, we find that the free tarps treatment decreased the probability of aflatoxin levels above the Ghanaian standard of 15 ppb by 8 percent and levels above the EU standard of 4 ppb by 6 percent. The market premium treatment decreased the probabilities by 5 and 6 percent, respectively.

Note that in this year of the study, all farmers had the same information on aflatoxin, its consequences, and post-harvest practices for its prevention. Thus, the effects on aflatoxin levels are due to the tarps or market premium offer conditional on information receipt. Given the strong effect of information on post-harvest practices we found in the first year of our study, it is likely the impacts would be even higher if measured using a pure experimental control.

Produced educational videos
With a Scaling Innovation through Video grant from USAID we produced a series of short videos on aflatoxin and aflatoxin prevention. One set of videos is aimed at extension agents or farmers themselves, and another video is aimed at researchers and development practitioners working on aflatoxin prevention. We screened these videos for field staff of the Ghana Trade and Livelihood Coalition, Peasant Farmers Association of Ghana, Northern Development Society, Grameen Ghana, Shea Network Ghana, and the Netherlands Development Organization. We are planning to disseminate and publicize these more widely in the near future.

Research achievements

Farmer training is effective at improving farmer post-harvest practices to reduce aflatoxin risk
Farmers in our study were totally unaware of aflatoxin before our intervention. While they were familiar with mold and the effect it has on palatability and marketability, they did not understand its health risks. Through our randomized control trial, we found training on improved post-harvest practices, particularly sorting and storage practices, was widely adopted and effective at reducing aflatoxin.

Few farmers will invest in tarps, but they will use them if they are provided free of charge
When we provided tarps free of charge, farmers gladly accepted them and nearly 70 percent used them for their intended purpose. However, even at subsidized prices ($2-$5 depending on quality) few farmers would pay for them. This kind of extreme price elasticity at low prices is similar to the well-documented case of demand for mosquito nets, and offers further evidence to support provision of free (or extremely subsidized) technologies that result in public benefits (in this case, improved food safety).

Farmers can be responsive to price premiums, but it requires flexibility
Offering farmers a price premium (in advance of harvest) for low aflatoxin groundnuts had no effect on post-harvest practices the first year we offered it. In the second year of our study we were more flexible in our purchases, offering to come within one week of the farmer's call, 3 to 7 months after harvest. We also offered a flat rate premium rather than a percentage to make the premium easier to understand. Under these conditions, in the three groups not offered the market premium roughly 20 percent reported successfully selling to our agent, whereas in the group offered the market premium 57 percent did. The higher sales rates in the second year are encouraging, but it is important to note that high value buyers are unlikely to offer this kind of flexibility to small farmers. For smallholder farmers it is unlikely that market forces alone will lead to aflatoxin safe groundnut production, at least as the market is currently structured. Thus, information about the health risks and assistance acquiring appropriate technologies are key.

Tarp distribution and offering a market premium can both be effective at lowering aflatoxin levels
Our interventions—coupled with training— resulted in lower aflatoxin levels where and when background aflatoxin levels were sufficiently high. Free tarp distribution reduced aflatoxin levels by over 30 percent and offering a market premium reduced levels by over 20 percent. These reductions were only achieved where and when background aflatoxin levels were not extremely low, as can be expected.

Policy presentation
Vivian Hoffmann presented our findings at the Workshop on Engaging the Health and Nutrition Sectors in Aflatoxin Control in Africa (Addis Ababa, Ethiopia), March 2016.The workshop was hosted by Global Alliance for Improved Nutrition, Partnership for Aflatoxin Control in Africa, Amref Health Africa, and the African Union).

Academic presentations
Nick Magnan presented our findings at the following invited seminars and conferences:

- Midwest International Economic Development Conference (University of Wisconsin-Madison), May 2017
- Agricultural and Applied Economics Association Annual Meeting (Boston), July 2016
- Department Seminar, University of Georgia Foods and Nutrition Department, April 2016
- Agricultural and Applied Economics Association section of the Allied Social Science Association Annual Meetings (Philadelphia), January 2018.

Vivian Hoffmann or Nick Magnan will also present at the International Conference for Agricultural Economists (Vancouver), July 2018

Technologies for Further Scaling and Adoption

Our research project did not produce any new technological innovations. We recommend the distribution of free drying tarps along with training on improved post-harvest practices.

Future Research Needs and Priorities

Measuring demand for aflatoxin-prevention technologies
Farmers appeared to value tarps, as they were happy to receive them and used them for their intended purpose when provided to them for free. They were effective at reducing aflatoxin. Purchase of tarps, however, was very low. While training on aflatoxin and aflatoxin prevention did increase tarp purchases, this could be simply because only farmers who underwent training knew where to purchase a tarp from the research team (tarps were not available in the villages otherwise).

New technologies such as Aflasafe and PICS bags may be very effective at preventing aflatoxin, but it is unknown if famers will use them, particularly if they need to pay. Further studies on demand for technologies are important to understand to what degree these technologies will have to be subsidized to get farmers to adopt them, and if there are any interventions (e.g., credit, information, social marketing, a market premium for aflatoxin safe groundnuts, etc.) that could increase demand. Experimental auctions or randomized coupons are potential approaches to studying demand.

How to purchase groundnuts cost-effectively from smallholder farmers
Smallholder farmers do not grow groundnuts as a commercial enterprise. Our research shows that they sell sporadically throughout the year when they need money, and also hold groundnuts long after harvest in the hopes the price will increase (as it generally does). These behaviors have two potential consequences for food safety.

First, because farmers do not want to sell large quantities of groundnuts, they will not be able to attract buyers that will pay a premium for quality. They will also not be able to have their production tested for aflatoxin in a cost effective manner. This reduces the monetary incentive to invest in aflatoxin-mitigating technologies, and results in more low quality and potentially high aflatoxin groundnuts ending up in local markets.

Second, these behaviors will result in groundnuts staying in suboptimal storage conditions. Farmers generally store groundnuts in a room in their compound, often with produce or other items. The facilities are not protected from insects, rodents, and moisture nearly as well as commercial warehouses. Ideally buyers would be able to purchase groundnuts shortly after harvest to put into large dedicated storage structures, but farmers are unwilling to sell their production at this point.

Our research shows that farmers can and will react to a market premium to produce safer nuts, but that implementing that market premium in a way that works for farmers is difficult and costly. More research on mechanisms that facilitate the purchase and proper storage of groundnuts, such as warehouse receipts, could help improve food security while also giving farmers flexibility and the opportunity for temporal arbitrage.

Nationwide longitudinal survey of aflatoxin in groundnuts and maize
Aflatoxin levels vary over space and time. To measure trends, and model what climactic (and other) factors influence aflatoxin levels, longitudinal data from throughout the country is required. Furthermore, identifying hotspots in the value chain where aflatoxin risk is especially high (storage at

the farm, transit, local markets, etc.), is an important step in understanding what interventions will be most effective at mitigating aflatoxin risks in society. The Opoku laboratory would like to be part of such an effort by systematically collecting and testing samples from throughout Ghana.

Prevalence of Trichothecene mycotoxins in maize and groundnuts in Ghana
Trichothecene mycotoxins, such as T-2 and HT-2 toxins, are toxic to humans and animals. They inhibit DNA and protein synthesis and cause a number of diseases. The climatic conditions in Ghana support their production, but little is known about their prevalence and concentration throughout the country.

Lessons Learned and Changes Made in Project Objectives

Expense and logistical difficulty of aflatoxin testing

Lessons learned

We found aflatoxin data very difficult to collect. Testing is expensive, and even more so when accounting for logistical issues involved with transporting groundnuts and keeping them refrigerated with frequent power disruptions. We needed to purchase two generators to keep groundnuts refrigerated.

Changes made

For the second and third round of aflatoxin data collection we switched from using Romer FluoroQuant testing to Mobile Assay. This method had lower variable costs, and much lower fixed costs (which for us were already sunk in purchasing the Romer fluorometer). A large advantage to this system is that it allowed us conduct quantitative tests in the field at the point of purchase, as opposed to taking temperature controlled samples back to the lab or use of semi-quantitative threshold strip tests). We found testing with the Mobile Assay system to be more accurate than the FluoroQuant system via testing of standards of known aflatoxin levels. However, neither test was as accurate as we expected or hoped.

Recommendation

We recommend using the Mobile Assay system for testing. We also recommend extensive training of testers and careful calibration using samples of known aflatoxin levels.

Aflatoxin levels vary greatly from year to year

Lesson learned

In our three years of aflatoxin testing from the same farmers, we found levels to vary greatly from year to year. Tests from the 2014-2015 season reveal very high levels, whereas tests from the 2015-2016 and 2016-2017 seasons were extremely low. Even within season, levels vary greatly. The high average levels of aflatoxin from 2014-2015 were largely the result of outlier samples with extremely high levels. These outliers were not present in 2015-2016 and 2016-2017. Such results are endogenous to aflatoxin contamination and careful consideration of sampling is required for future research.

Changes made

The large drop in aflatoxin levels from the 2014-2015 season to the 2015-2016 season was a major reason for us to test our interventions again in 2016. This turned out to be a good research investment, as in the Northern Region (but not the Upper East) background aflatoxin levels were high enough to make and detect an impact.

Recommendations

Year-to-year variability in aflatoxin levels makes it difficult to make general claims from any evaluation that uses aflatoxin levels as an outcome of interest. If background aflatoxin levels are low, as they were in our two years of post-intervention data collection, it may not be not be possible to show impact of interventions that may be very impactful in years when aflatoxin levels are higher. We recommend for any study that uses aflatoxin levels as an outcome to conduct multi-site, multi-year studies in order to be able to test for impacts under a variety of climatic conditions. This is very expensive, however, and may not be possible given budget constraints.

Farmers are very reluctant to sell their groundnuts, even at a premium

Lessons learned

As stated above, farmers were very reluctant to sell us their groundnut production 2-3 months after harvest. Our scoping survey indicated that this is when farmers sold most of their production from the 2014 harvest, but perhaps that was an exceptional year. When we tried to purchase groundnuts 2-3 months after the 2015 harvest, only seven of nearly 1,000 farmers sold to us. When asked why they did not, many indicated they were waiting for when they needed money, or for when the price would rise.

Changes made

For our second attempt to purchase groundnuts we offered farmers more flexibility. They could call us any time after harvest and within a week we would send a buyer. Only 31 farmers sold to one of our buyers 3 months after harvest, but 100 did so by 7 months, and 200 indicated trying to sell (but many did not ultimately do so because the offer price was too low).

Recommendations

The approach we took to buying groundnuts is likely cost prohibitive to actual groundnut buyers. We recommend more research on ways to incite farmers to sell their groundnuts in large quantities, shortly after harvest, in an effort to better integrate them into value chains that reward quality and safety.

Project C4. Aflatoxin Management Interventions, Education and Analysis at Various Steps Along the Peanut Value Chain in Malawi, Mozambique and Zambia

This project addressed a wide range of production, post-harvest handling, and processing issues relative to peanuts in Malawi, Zambia, and Mozambique that can impact aflatoxin contamination levels, yield, and profitability. The strength of this project was that interventions were evaluated throughout the value chain and the cumulative effect of these efforts was measured against traditional production and marketing practices. Through linkages with various partners, farmer education was also emphasized and extended linkages with various industries and marketing groups have helped accelerate aflatoxin mitigation and market development.

Malawi has a strong history of research on peanut through ICRISAT, the Department of Agriculture Research Services at Chitedze Research Station (DARS), and Lilongwe University of Agriculture and Natural Resources (LUANAR), but the ability of farmers to produce high yielding, high quality peanuts with consistently low aflatoxin levels is still quite limited. Additional agencies such as NASFAM (National Small Farmer Association of Malawi), the Ministry of Agriculture, Exagris Africa Ltd, Afri-Nut, TWIN trading of the U.K., the Clinton Development Initiative and others are all engaged in further evaluation of production, processing, and marketing strategies as well as farmer education. Improved cultivars are available, but the lack of an effective seed program limits availability. Limited marketing due to high aflatoxin contamination levels exacerbates the problem by reducing farmer incentive to implement current production recommendations and limits commercial processing and marketing.

Our project, with its multidisciplinary team, took a comprehensive approach to problem-solving research and effective technology transfer through key partnerships with in-country research counterparts and NGOs. The intention of the project was to take the higher level of peanut research in Malawi and to rapidly phase extension into Zambia and Mozambique, creating a regional project providing research data with even wider scale application. Key components included taking advantage of already available improved germplasm, in-country aflatoxin testing equipment and technicians already in place, as well as key production, processing, marketing and technology transfer partners. Our project addressed the challenges from production to processing including information transfer and creating aflatoxin awareness along the whole value chain.

Achievements

The pre-harvest component of the project has been very focused and productive. Primary objectives were to evaluate production practices that resulted in increased yields, increased profits, and improved crop quality (reduced aflatoxin). Six students (5 MSc and 1 PhD) were funded across 3 countries in the pre-harvest component of the value chain project. They focused on planting date, plant populations, soil amendments, crop rotation, pest management, harvest date, and drying technique. The cumulative results of this research allows us to fully understand the individual value of various production regimes and input in the production of profitable peanuts in the three host countries. The valuable findings from these studies were the result of unique and highly motivated collaborative linkages among non-traditional partners. These linkages included national research and CGIAR centers, universities and the private sector. Key to success was the linkage of ICRISAT-Malawi and Exagris to LUANAR for graduate research and training. This provided students with an unmatched opportunity to conduct large-scale plot research at facilities that could ensure a high level of quality control and plot maintenance. Additionally, our linkage with Exagris and the peanut breeding program at DARS provided opportunities for evaluation of advanced lines in diverse agroecological zones and provided a mechanism for seed multiplication and deployment to out-grower farmers. While the students have produced numerous refereed science journal articles (which is a positive reflection of the quality of the research), more importantly, the research has addressed critical research needs for peanut production in these countries.

Likewise, the post-harvest research component has produced excellent results, primarily through six (MSc) student led projects.

To date, six students completed degrees in pre-harvest fields (one PhD) and six students completed degrees in post-harvest areas.

Post-harvest Interventions
Malawi

- Groundnut flour standards were developed and practices of blanching and variable temperature roasts were compared against the standards for quality measures of aflatoxin, microbial levels and rancidity or shelf life. Project led to development of official Malawi Bureau of Standards new groundnut flour standards.
- Different extraction methods for producing peanut oil were analyzed for their efficiency in preventing aflatoxin carryover.

- Farmers were surveyed about their knowledge of how drying and storage can affect aflatoxin contamination. Drying and storage technologies were tested for their effectiveness in limiting aflatoxin contamination.
- Development and Evaluation of Technologies and Practices for Cleaning and Sorting Groundnuts

Mozambique

- Planting and harvest dates were evaluated for impact on yield and quality, demonstrating the yield loss when farmers wait too long to plant (until after a more-valuable cash crop is in the ground) or leave mature peanuts in the ground too long (while they harvest other crops.)

Zambia

- Tests were conducted using six common methods for drying peanuts. Concrete slab and papyrus mat surfaces showed higher drying performance at 2.13 and 2.07% dry basis per hour, therefore, concrete slab and papyrus mat surfaces with depth of 3.6cm were the most effective drying methods to reduce aflatoxin contamination.
- A market survey was conducted for the prevalence of aflatoxins in three peanut products: raw peanuts, powdered (milled flour) peanuts and roasted peanuts sold in open markets of 14 districts. Faculty at the University of Zambia conducted the survey and continues to analyze the data in order to prepare a manuscript.
- Three Zambian groundnut varieties (Kadonongo, Makulu Red and Chalimbana) were analyzed for shelf life stability of peanut butter. The study was conducted by an MSc Chemistry student who is currently working on his thesis.
- A study of two Zambian peanut varieties (Kadonongo and Chalimbana) evaluated ecological fungal changes occurring in the raw peanuts and processed peanut butters (during production and storage) using molecular techniques. The master's student in molecular biology who is conducting the research also assessed the aflatoxin content and changes over time. She continues work on her thesis.
- A master's student in human nutrition conducted a study on groundnut-processing practices and aflatoxin exposure among children age 6 months to 35 months in a peri-urban community in Lusaka. The student is doing data analysis and thesis writing
- A bachelor of science student in food science and technology studied the physicochemical properties and sensory evaluation of peanut butter made from three Zambian groundnut varieties (Kadonongo, Makulu Red and Chalimbana). The student completed her dissertation, and there is a manuscript under preparation for possible journal publication.

USA (University of Georgia)

- Storage quality of lightly roasted, shelled peanuts was compared with raw shelled nuts.

Technologies for Further Scaling and Adoption

Pre-harvest:

- Farmers should consider pre-rain "dry" planting. Data suggested that this increased yield and reduced the likelihood of aflatoxin. This will be a challenge for prioritization.
- Increased plant density from current farmer practice should be encouraged.
- Timely harvest should be a focus of farmer training to maintain yield and quality.

Post-Harvest:

- The various drying techniques and conditions that have been explored by both LUANAR and UNZA can be disseminated to the peanut growers in the respective countries.

- The light roasting of raw peanuts followed by blanching can be an effective tool to weed out discolored peanuts thereby decreasing the chances of aflatoxin contamination. Moreover, if the blanched peanuts are stored in HDPE bags, the shelf life is around 32 weeks. This technology can be transferred easily to the peanut processors.
- LUANAR can help implement GMP/HACCP through training and workshops as they have developed the related training modules.
- Both LUANAR and UNZA should be able to help small and medium processors with their processing needs.

Future Research Needs and Priorities

Pre-Harvest:

- Research in various production areas on complete production tech packages with new varieties compared to CG7. These trials should be conducted on commercial farms, on out grower farms, and in separate farming villages and subjected to economic analysis.
- Forecast models should be developed and integrated for crop maturity and optimal harvest dates for consumption and for seed, predictive models for aflatoxin

Post-Harvest:

- Transportation and storage studies should be continued to be studied to reduce the incidence aflatoxins in harvested/dried in-shell peanuts. Various cost effective packaging materials should be studied. Traceability should also be a major focus in the next phase.
- The push for high-quality products from microbiological, toxicological, nutritional and sensory viewpoints should be maintained.
- Nutritional studies showing the positive impact of peanuts on children and maternal health should be made a priority area of research in future.
- Characterizing all the local peanut cultivars of the host countries for flavor, physicochemical, nutritional and sensory properties should be carried out.
- There should be an emphasis on short training for more students and staff from the host countries at the collaborating US universities.

Lessons Learned and Changes Made in Project Objectives

Malawi

- The majority of groundnut flour processors are unaware of aflatoxin and practices required to reduce aflatoxin risk. A survey of the market found that the majority of flours do not meet quality and safety standards.
- While commercial oil extraction yields oil with low aflatoxin levels, simple village-scale methods lend a false sense of security that aflatoxin levels are low when they can be significant. A study of simple methods, such as blanching, filtration and ethanol cleansing showed the most effective ways to reduce aflatoxin to acceptable levels.
- Groundnuts dried together with vines took 14 days to dry compared with threshed nuts that took only three days to dry, but also had a high percentage of splits, discoloration and mold. Storage studies reveal that the use of polyethylene bags for storing groundnuts might result in high aflatoxin contamination as compared to storing the groundnuts in hermetically sealed bags and in the traditional granary.

Mozambique

- Early planting and timely harvest showed significantly improved yields and reduction of aflatoxin. Contrary to a common misconception of farmers in the region, harvesting 10 days past maturity brought in 30.7% to 36.6% fewer of the pods, compared to timely harvest. Farmers and extension agents can use this knowledge to weigh the cost of delaying another activity or hiring labor to harvest peanuts on time.

Zambia

- Existing drying methods/surfaces were identified and evaluated for optimal materials and peanut depth to reduce aflatoxin contamination. Concrete slab and locally made papyrus mats were found to be an improvement over bare ground.

USA (University of Georgia)

- Hermetic storage extends shelf life of both blanched and unblanched peanuts for 24 weeks. Woven poly bags should be avoided due to limited oxygen barrier and likelihood of rancidity.

Project Management

The coordination of a true value chain project, its deployment and promotion of a team concept, as well as the logistics of coordinating the projects and proving sub awards and funding in a timely manner was a disaster the first two years of the project. The delay in getting the funds, the addition of new countries and institutions that no one from the U.S. side had any interaction with or a previous working relationship made the initiation of the project burdensome and frustrating for all (especially host country collaborators). The need to rapidly develop relationships, new objectives, collaborators, and MOUs after the project has already started resulted in programs that were slow to start, mistrust among the collaborators, and frustration at every level. If the intent is to fund only a value chain that includes pre and post-harvest over multiple countries that needs to be clear in the call for proposal and not a contingency for funding once the awards are made.

The main lesson learned was about the disbursement of the funds. From year 3 it was decided that the funds will be disbursed quarterly to the host countries in the form of an advance. This helped the host countries tremendously as they did not have find the funds on their own to spend before being reimbursed by UGA. The previous format actually hindered the progress of the project in the first 2 years.

Project C5. Productivity and Profitability Growth in Peanut Production: A Farm Level Analysis in Malawi, Mozambique and Zambia

The overarching objective of this project was to generate and transfer economic knowledge needed to intensify groundnut production, and its subsequent use, so as to significantly increase productivity and farm profits, while reducing the risk of aflatoxin contamination in the harvested crop. The end goal was to boost productivity growth in groundnut farming systems as a way to increase food safety, food security, and farm income in Malawi, Mozambique, and Zambia. This work has been done in close collaboration with the Southern Africa Value Chain and Integrated Breeding Projects.

A fundamental underpinning of the project was that a major constraint to a healthy groundnut value chain in much of Africa is low levels of farm productivity and profits. Productivity and profits can be improved in various ways, including gains in marketable yields. Thus, the primary focus of this project was to analyze the farm level costs and benefits of alternative treatments designed to reduce the aflatoxin levels with the goal of increasing peanut quality and prices received by farmers.

A second area of work was to utilize available data from the World Bank Living Standard Measurement Studies-Integrated Surveys on Agriculture (LSMS-ISA) and variety data generated by the Integrated Breeding Project to evaluate the farm benefits of improved seed varieties, particularly in Uganda and Malawi.

A third area of work was to undertake human capacity building through workshops in various topics including production economics, farm management principles and/or impact evaluation techniques.

Achievements

The project has taken shape under two primary objectives: 1) Compiling, organizing and analyzing existing productivity data through collaboration with other PMIL initiatives (including Ghana), particularly the breeder network, and 2) implementation of a baseline survey in Mozambique.

Objective 1:

- A database for the project has been completed and will be made available to researchers.
- Data collection over the last year by country included:
    - Malawi: Information received for planting and harvest date, planting density, drought stress, and varietal trials for most recent growing seasons.
    - Zambia: Communications with local researchers continued, but data was not made available for analysis.
    - Mozambique: Additional data was received, but not included in the ongoing analysis because it is different than the data already available and could not be merged to conduct a unified analysis.
- The following research manuscripts are in final stage of preparation for submission to scholarly journals:
    - Groundnut Yields from Alternative Seed Varieties: Economic Evidence from Mozambique and Malawi. Bravo-Ureta, B. E., J. Jelliffe, E. Owusu, A. Muitia, C. Sibakwe, N. Puppala, C. Deom, J. Chintu. Objective: To examine productivity of interventions designed to decrease aflatoxin based on seed varietal trials conducted in Mozambique and Malawi.
        1) Mozambique (720 observations):
            a) Outcome variable: Yield in four study locations (Namapa, Nampula, Montepuez and Ancuabe) for four seasons 2012/13, 2013/14, 2014/15 and 2015/16 (unbalanced panel).
            b) Treatment variables: - Groundnut varieties (JL-24, ICGV-SM01513, ICGV-SM01514, ICGV-SM99568 and ICGV12991; Planting dates (December 15, December 24, January 3 and January 13).
        2) Malawi (60 observations):
            a) Outcome variable: - Yield over two growing seasons (2014 to 2016)
            b) Treatment variables: - Groundnut varieties (ICGV-SM01514, Chitala, Baka, Kakoma, and ICGV-SM99566); Moisture stress (no, mild, moderate/minimal and prolonged drought).

- Productivity and Profitability Effects of Alternative Groundnut Management Practices in Malawi and Ghana. Bravo-Ureta, B. E., J. Jelliffe, E. Owusu, L. Mkandawire, M. Abudulai, B. Mochiah, D. Jordan, R. Brandenburg . Objective: To examine cost and benefits of alternative management interventions designed to improve productivity and profits in Malawi and Ghana.

1) Malawi (384 observations):
   a) Outcome variable: - Gross Margin in two study locations (Mpatsanjoka and Lisungwi) for two seasons- 2015/16 to 2016/17 (balanced panel).
   b) Treatment variables: - Season (dry, rainy); Days to harvest; Planting density (89,000 plants/ha, 178,000 plants/ha, 285,000 plants/ha).
2) Ghana North (144 observations):
   a) Outcome variable: - Gross Margin for 2015/16 growing season in two locations (Zankali and Kpalbe);
   b) Treatment variables: - Fertility Management Practices (Yara Legume, Oyster Shell, Farmer Practice).
3) Ghana South (48 observations):
   a) Outcome variable: - Gross Margin for 2015/16 growing season in two locations (Drobonso and Ejisu)
   b) Treatment variables: - Fertility Management Practices (Alata soap & Oyster Shell, Farmer Practice).

Objective 2:
Analysis of the data from the June 2016 Mozambique diagnostic survey commenced and preliminary results are incorporated into a graduate student dissertation research proposal. The final analysis will be included in a journal article submission. Initial findings indicate low-level mean productivity and technical efficiency among smallholder farmers in northern Mozambique. These results are consistent with reports from local experts and prior research findings from farm-level trials. This survey will serve as a rigorous baseline for future interventions.

Capacity Building and Training:
A graduate student attended a 1-week training program at the World Bank headquarters in Washington D. C. to learn how to use the Survey Solutions tool. This is a tablet driven application to collect survey data.

Training of 20 individuals focusing on survey design and implementation was completed in Malawi. The training included survey preparation, basics of impact evaluation, and the use of tablets for data collection following the methods and software used by the World Bank.

Technologies for Further Scaling and Adoption

The data received from field trials indicate that early planting results in greater yields. Results from varietal trials in Malawi and Mozambique provide evidence of superior performance of certain varieties compared with others. However, in Mozambique only new varieties are compared and the study did not include a land race or traditional variety for the sake of comparison to typical farmer practice. It is therefore recommended that scaling and adoption of recommended practices for planting date and varietals be seriously considered.

Future Research Needs and Priorities

It is possible to utilize the information collected during the diagnostic survey to evaluate adoption of alternative management practices at baseline, e.g., planting date and varietal. Following a scaling up and dissemination program, researchers can revisit the same HHs to evaluate the impact of adoption of alternative management practices. It is important to note the importance of research design for any prospective dissemination programs in order to capitalize on the available baseline data. Randomization and careful selection of 'treated' and 'control' HHs should be given primary attention. In this case, it is usually recommended that randomization be done at the village level.

Lessons Learned and Changes Made in Project Objectives

It is critical to have closer coordination from the beginning across similar projects regarding objectives, data collection approach, and eventual analysis. Undertaking similar objectives across different landscapes can be a real strength of programs like PMIL, but to be able to take full advantage of comparative work requires harmonization of protocols from the outset.

The training received and given regarding the World Bank Survey Solutions tool has clearly shown that this type of approach should be implemented whenever possible. An example of a promising area of application is for the data collection from variety trials. Training peanut breeders and technicians on how to use Survey Solutions would significantly enhance the value of the final data they generate.

Human and Institutional Capacity Development

Short-Term Training (by country)

Name	Gender	Home Country	Home Institution	Dates	Discipline	Research Focus	Mentor	Training Location
Abdi Hassen	M	Ethiopia	Hawassa University, Awassa, Ethiopia	06/28/2017-07/08/2017	Plant Pathology	Detection of aflatoxin types and molecular diversity of *Aspergillus* species from Ethiopia	Renee Arias	USDA-ARS National Peanut Research Lab, Dawson, GA, USA
Fidele Neya	M	Burkina Faso	University of Ouagadougou		Plant Pathology	Training in genomics, specifically identification and use of SNP-based markers	Mike Deom	Texas A&M Agrilife Research
Maxwell Lamptey	M	Ghana	Crops Research Institute, Kumasi, Ghana	Apr-Sep/2015	Agricultural mechanization	Develop and evaluate a solar dryer for peanuts	Jinru Chen/David Jordan	University of Georgia, Griffin, GA USA
Junior Abraham	M	Haiti	Universite ROI Henri Christophe	2017	Agriculture Science	Internship and undergraduate thesis (Seed Spacing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin. Med and Food for Kids
Wendy Antoine	M	Haiti	Universite Roi Henri Christophe	April 2017	Agriculture Science	Internship and undergraduate Thesis (Planting Methods)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Gary Benoit	M	Haiti	Universite Roi Henri Christophe	Spring 2016		Internship and undergraduate thesis (Runner Fungicide Timing Study)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Emile Blaise	F	Haiti	Universite ROI Henri Christophe	2017	Agriculture Science	Internship and undergraduate thesis (Seed Spacing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids

Name	Gender	Home Country	Home Institution	Dates	Discipline	Research Focus	Mentor	Training Location
Rolcky Butois	M	Haiti	Universite Chretienne du Nord d'Haiti	October 2016	Agriculture Science	Internship and undergraduate thesis (Runner Fungicide Timing Study)	Rick Macajous/Alex Carroll/ Greg MacDonald	Quartier Morin/ Med and Food for Kids
Fedeline Charles	F	Haiti	Universite ROI Henri Christophe	2017	Agriculture Science	Internship and undergraduate Thesis (Runner Fungicide Timing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Pierre Richard Charles	M	Haiti	Universite Episcopale d'Haiti	April 2017	Agriculture Science	Internship and undergraduate thesis (Planting Method)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Mirebalais
Rodson Charles	M	Haiti	Universite Solidarite d'Haiti	March 2017	Agriculture Science	Internship and undergraduate thesis (Runner Fungicide Study)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Exan Desamours	M	Haiti	Universite Roi Henri Christophe	Fall 2016		Internship and undergraduate thesis (Runner Fungicide Timing Study)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Dapheney Dolce	F	Haiti	Universite Roi Henri Christophe	March 2017	Agriculture Science	Internship and undergraduate thesis (Soil Fertility)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Laine Dorinvil	M	Haiti	Universite Roi Henri Christophe	Fall 2016		Internship and undergraduate thesis (Top 6 Valencia Study at Quartier-Morin)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids

Name	Gender	Home Country	Home Institution	Dates	Discipline	Research Focus	Mentor	Training Location
Ruth Eustache	F	Haiti	Universite Roi Henri Christophe	April 2017	Agriculture Science	Internship and undergraduate thesis (Seed Spacing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Jean Baptiste Fontilus	M	Haiti	Universite Chretienne du Nord d'Haiti	January 2017	Agriculture Science	Internship and undergraduate thesis (Top 6 Valencia Study at Quartier-Morin)	Rick Macajoux/ Alex Carrol/Greg MacDonald	Quartier Morin/Med and Food for Kids
Rosiny Frederick	M	Haiti	Universite Roi Henri Christophe	2017	Agriculture Science	Internship and undergraduate thesis (Seed Spacing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Pierre Galet	M	Haiti	Universite Chretienne du Nord d'Haiti	Fall 2016		Internship and undergraduate thesis (Plant and Seed Spacing Study)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Daphenie Jean	F	Haiti	Universite Roi Henri Christophe	2017	Agriculture Science	Internship and undergraduate thesis (Runner Fungicide Timing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Rodlin Jean	M	Haiti	Universite Roi Henri Christophe	2017	Agriculture Science	Internship and undergraduate thesis (Seed Spacing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Ronald Jean	M	Haiti	Universite d'Etat d'Haiti, Campus Roi Henri Christophe	April 2017	Agriculture Science	Internship and undergraduate thesis (Soil Fertility)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids

Name	Gender	Home Country	Home Institution	Dates	Discipline	Research Focus	Mentor	Training Location
Joseph Job	M	Haiti	Universite Roi Henri Christophe	April 2017	Agriculture Science	Internship and undergraduate thesis (Planting Method)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Fredo Joseph	M	Haiti	Universite Roi Henri Christophe	2017	Agriculture Science	Internship and undergraduate thesis (Seed Spacing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Jean Jones Joseph	M	Haiti	Universite Chretienne du Nord d'Haiti	October 2016	Agriculture Science	Internship and undergraduate thesis (Advance Breeding Line Study: Tillman Variety)	Rick Macajoux/ Alex Carroll/ Greg MacDonald	Quartier Morin/Med and Food for Kids
Judeline Joseph	F	Haiti	Universite Chretienne du Nord d'Haiti	Fall 2016		Internship and undergraduate thesis (Soil Amendment Study)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Myrvelisa Jules	F	Haiti	Universite Roi Henri Christophe	April 2017	Agriculture Science	Internship and undergraduate thesis (Seed Spacing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Elize Leandre	M	Haiti	Universite Chretienne du Nord d'Haiti	2017	Agriculture Science	Internship and undergraduate thesis (Valencia Fungicide Timing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Yonel Louis	M	Haiti	Universite Chretienne du Nord d'Haiti	April 2017	Agriculture	Internship and undergraduate thesis (ICRISAT Variety)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids

Name	Gender	Home Country	Home Institution	Dates	Discipline	Research Focus	Mentor	Training Location
Rico Mondestin	M	Haiti	Universite Roi Henri Christophe	2017	Agriculture Science	Internship and undergraduate thesis (Seed Spacing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Galeine Queranor	F	Haiti	Universite Roi Henri Christophe			Internship and undergraduate thesis (Valencia Fungicide Timing Study)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Junie Pachoute	F	Haiti	Universite Roi Henri Christophe	2017	Agriculture Science	Internship and undergraduate thesis (Seed Spacing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Frisnel Pierre	M	Haiti	Universite Roi Henri Christophe	Fall 2016		Internship and undergraduate thesis (Top 6 Valencia Study at Quartier-Morin)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Kinson Pierre	M	Haiti	Universite Roi Henri Christophe	2017	Agriculture Science	Internship and undergraduate thesis (Runner Fungicide Timing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med & Food for Kids
Telson Richard	M	Haiti	Unviersite Solidarite d'Haiti	March 2017	Agriculture Science	Internship and undergraduate thesis (Valencia Fungicide Timing)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids
Norvilmar St Firmin	M	Haiti	Universite Roi Henri Christophe	March 2017	Agriculture Science	Internship and undergraduate thesis (Planting methods)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Quartier Morin/Med and Food for Kids

Name	Gender	Home Country	Home Institution	Dates	Discipline	Research Focus	Mentor	Training Location
Rodemane Saint Louis	F	Haiti	Universite Roi Henri Christophe	Fall 2016		Internship and undergraduate thesis (Top 6 Valencia study)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Marilene Saint-Juste	F	Haiti	Universite Roi Henri Christophe	Fall 2016		Internship and undergraduate thesis (Valencia Fungicide Timing Study)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
Rodnie Valmy	F	Haiti	Unviersite Roi Henri Christophe	Spring 2016		Internship and undergraduate thesis (Top 6 Valencia Study)	Rick Macajoux/ Alex Carroll/Greg MacDonald	Med and Food for Kids
David Githanga	M	Kenya	University of Nairobi	September 7 – September 15, 2017		Aflatoxin Detection	JS Wang	University of Georgia
Paul Macharia	M	Kenya	Kenyatta University	2015	Biotechnology	Peanut-genetic transformation and molecular tools	Renee Arias	USDA-ARE National Peanut Research Lab, Dawson, Ga USA
Daniel Mwalwayo	M	Malawi	Malawi National Standard Bureau	October 11- October 30, 2016		Aflatoxin Detection	JS Wang	University of Georgia
Vincent Mlotha	M	Malawi	Lilongwe University of Agriculture and Natural Resources			Sensory and Aflatoxin techniques	Agnes Mwangwela	University of Georgia; Virginia Tech
Amos Acur	M	Uganda	NARO, Uganda	2015	Molecular diversity	Isolation and genetic fingerprinting of *Arpergillus*	Renee Arias	USDA-ARS National Peanut Research Lab, Dawson, GA, USA
Jonothan Farr	M	USA	Georgia Southwestern Univeristy			Learn molecular tools and help with research projects	Renee Arias	USDA-ARS National Peanut Research Lab, Dawson, GA, USA

Name	Gender	Home Country	Home Institution	Dates	Discipline	Research Focus	Mentor	Training Location
LaTanya Johnson	F	USA	Albany State University	2014-2015	Biotechnology	DNA extraction from *Aspergillus* and from plants, PCR screenings, and DNA fingerprinting	Renee Arias	USDA-National Peanut Research Laboratory, Dawson, GA USA
Austin Page	M	USA	Albany State University		Biology	Learn molecular tools to help with research projects	Renee Arias	USDA-National Peanut Research Laboratory, Dawson, GA USA
Emily Urban	F	USA	University of Georgia	2016		Survey preparation and facilitation	Boris Bravo-Ureta	
Loveness Nyanga	F	Zimbabwe	University of Zimbabwe	January 15-February 6, 2017		Aflatoxin Detection	JS Wang	University of Georgia

Degree Long-Term Training (by country)

Name	Gender	Home Country	Degree	Graduation Date	Discipline	Research Focus	Mentor	Training Institution
Paola Faustinelli	F	Argentina	PhD	2012	Plant Biotechnology		Renee Arias	University of Cordoba, Argentina
Fidele Neya	M	Burkina Faso	PhD	April 2017	Plant Pathology		Carl Deom	Universite de Ouagadougou, Burkina Faso
Samson Nakone	M	Burkina Faso	MS		Plant Pathology		Carl Deom	Universite de Ouagadougou, Burkina Faso
Kouha Hamidou Sogoba	F	Burkina Faso	MS		Plant Pathology		Carl Deom	Universite de Ouagadougou, Burkina Faso
Adama Zongo	M	Burkina Faso	PhD	2014			Carl Deom	
Wenjie Cai	F	China	MS	May 2018	Environmental Health Science		JS Wang	University of Georgia
Fengle Zhu	F	China	PhD	July 2014	Biosystems Engineering		Haibo Yao	Zhejiang University, China

Name	Gender	Home Country	Degree	Graduation Date	Discipline	Research Focus	Mentor	Training Institution
Carolina Chavarro	F	Columbia	PhD	August 2017	Plant Breeding, Genetics and Genomics		Peggy Ozias-Akins	University of Georgia , Tifton GA USA
Alibu Abdul-Hafiz	M	Ghana	BSc	November 2016	Bio-Technology		Nelson Opoku	University for Development Studies
Yussif Abubakari	M	Ghana	MPhil	November 2016	Food Science and Technology	Effects of applications of calcium to reduce aflatoxin contamination in peanut	David Jordan	Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
Isaac Kwesi Addo	M	Ghana	MSc	July 2016	Food & Postharvest Engineering	Determining the utility of drying methods including fabricating a solar dryer to reduce aflatoxin in peanut	David Jordan	Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
Boadi Gershon Afoakwah	M	Ghana	BSc	July 2017	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies (UDS)
Esther Yeboah Akoto	F	Ghana	MSc	December 2016	Food Science	Deactivation of aflatoxin-contaminated peanut waste via composting	Jinru Chen	University of Georgia. Griffin, GA USA
Theophilus Alale	M	Ghana	MPhil	November 2015	Biotechnology		Nelson Opoku	University for Development Studies (UDS)
Abraham Anane	M	Ghana	BSc	July 2017	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies (UDS)
James Addy Appenahier	M	Ghana	BSc	July 2017	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies (UDS)
Obed Boadi Asumah	M	Ghana	BSc	July 2017	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies (UDS)
Stephen Arthur	M	Ghana	MPhil	Jul 2017	Agronomy	Influence of herbicides and fungicides on pest reaction, yield, and aflatoxin in peanut	David Jordan	Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
Ayinu Asumah	M	Ghana	BSc	July 2016	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies (UDS)
Abigail Awusiwa	F	Ghana	BSc	July 2017	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies(UDS)

Name	Gender	Home Country	Degree	Graduation Date	Discipline	Research Focus	Mentor	Training Institution
K. Emmanuel Ayenor	M	Ghana	BSc	July 2017	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies
Raphael Kwasi Ayim	M	Ghana	BSc	July 2017	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies (UDS)
Erica Azatorwu	F	Ghana	BSc	July 2017	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies (UDS)
Sylvia Baah-Tuahene	F	Ghana	MSc	Nov 2015	Food Science	Evaluating the quality (aflatoxin and microbial) of products in the local peanut processing chain	Agnes Budu, F.K. Saalia	University of Ghana, Accra, Ghana
Eric Biney	M	Ghana	BSc	July 2017	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies (UDA)
Clara Darko	F	Ghana	PhD	December 2016	Agriculture Engineering/ Post-harvest Processing	Comparison of storage systems for in-shell, shelled, and blanched peanuts	Kumar Mallikarjunan/ David Jordan	Virginia Tech
Isaac Darko	M	Ghana	MPhil	November 2016	Agriculture Engineering		Kumar Mallikarjunan/ David Jordan	Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
Loretta Darkwah	F	Ghana	MSc		Food Science	Groundnut processing	Agnes Budu, F.K. Saalia	University of Ghana, Accra, Ghana
Joshua Kweku Ayim	M	Ghana	BSc	July 2017	Biotechnology and Molecular Biology		Nicholas Magnan	University for Development Studies (UDS)
Afia Karikari	F	Ghana	PhD		Breeding		James Asibuo	Crops Research Institute
Dominic Ndela Ngagmayan	M	Ghana	BSc	November 2016	Biotechnology		Nelson Opoku	University for Development Studies
B.A. Charles Neequaye	M	Ghana	BSc	November 2016	Biotechnology		Nelson Opoku	University for Development Studies (UDS)

Name	Gender	Home Country	Degree	Graduation Date	Discipline	Research Focus	Mentor	Training Institution
Vincent Ninkuu	M	Ghana	MPhil	January 2017	Biotechnology	Leading enumerator teams, conducting laboratory testing, and doing data analysis	Nelson Opoku	University for Development Studies (UDS)
William Ofori Appaw	M	Ghana	MPhil	November 2017	Food Science and Technology	Includes evaluation of pre- and post-harvest interventions to reduce aflatoxin in peanut	David Jordan	Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
Eric Owusu	M	Ghana	PhD	May 2020	Ag Economics		Boris Bravo-Ureta	University of Connecticut
Noah Saduli	M	Ghana	MPhil	October 2016	Biotechnology	Leading enumerator teams, conducting laboratory testing, and doing data analysis	Nelson Opoku	University for Development Studies, (UDS)
Theophilus Tengey	M	Ghana	PhD	August 15, 2018	Plant and Soil Science	DNA markers for resistance to leaf spot	Carl Deom	Texas Tech University
Maxwell Yorke	M	Ghana	BSc	November 2016	Biotechnology		Nelson Opoku	University for Development Studies
Paul Karanja	M	Kenya	MSc	December 2014	Plant Biotechnology	Genetic transformation of peanut using RNA interference construct provided by NPRL	Renee Arias	Kenyatta University, Kenya
Davis Gimode	M	Kenya	PhD	May 2019	Plant Breeding, Genetics and Genomics	Peanut genomics	Peggy Ozias-Akins	University of Georgia, Tifton, GA USA
Ruth Wagina	F	Kenya	PhD	May 2020	Environmental Health Science		J.S. Wang	University of Georgia
Andrew Abraham	M	Malawi	MSc	September 2016	Crop Science	Effect of rotations and harvest date on pre-harvest aflatoxin contamination	W. Mhango, V. Saka/R. Brandenburg	Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Kelita Phambala	F	Malawi	B.S.	2016	Agronomy	Isolation of Aspergillus from soil and peanuts	Sam Njoroge/ Renee Arias	
Ruth Phiri	F	Malawi	B.S.	2016	Agronomy	Isolation of Aspergillus from soil and peanuts	Sam Njoroge/ Renee Arias	

Name	Gender	Home Country	Degree	Graduation Date	Discipline	Research Focus	Mentor	Training Institution
Kobby Amponsah	M	Malawi	MSc	2015	Economics	Research Technician working on the productivity effects of improved groundnut seed varieties	Boris Bravo-Ureta	University of Connecticut
Albert Jere	M	Malawi	BSc	November 2017	Nutrition and Food Sciences	Effects of blanching and variety of peanut on sensory characteristics of cooked pumpkin leaves seasoned with peanut flour	Agnes Mwangwela	Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Prince Chadza	M	Malawi	BS	July 2017	Agriculture Engineering		Agnes Mwangwela	Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Monica Chimbaza	F	Malawi	MSc	June 2017	Agricultural Engineering	Drying and storage technologies for reducing aflatoxin in peanuts	Wellam Kamthunzi	Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Aggrey Gamma	M	Malawi	PhD	May 2019	Food Science	Peanut products	Koushik Adhikari	University of Georgia, Griffin, GA USA
Clara Kasukula	F	Malawi	MSc	Apr 2017	Food Science	Residual aflatoxin in oil from contaminated peanuts	Limbikani Matumba	Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Jeremy Jelliffe	M	Malawi	PhD	December 2017	Economics	Economics of interventions to reduce aflatoxin contamination in peanuts	Boris Bravo-Ureta	University of Connecticut, Storrs, CT USA
Chikondi Magombo	F	Malawi	MSc	Mar 2017	Food Science	Processing and uses of peanut flour	Agnes Mwangwela	Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Esther Mambo	F	Malawi	BS	2014	Biology	Isolation of Aspergillus from soil and peanut samples	Renee Arias	University of Malawi, Chancellor College

Name	Gender	Home Country	Degree	Graduation Date	Discipline	Research Focus	Mentor	Training Institution
Dickson Mbughi	M	Malawi					Renee Arias	
Lydia Mkandawire	F	Malawi	MSc	November 2017	Agronomy		Agnes Mwangwela/R. Brandenburg	Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Tchiyiwe Moyo	F	Malawi	MSc	February 2016	Food Science	Baseline evaluation of peanut butter quality and processor knowledge of aflatoxin	Agnes Mwangwela	Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Chancy Sibakwe	M	Malawi	MSc	September 2016	Entomology	Biotic/Abiotic stress impacts on pre-harvest aflatoxin contamination	W. Mhango, V. Saka/R. Brandenburg	Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Longwe Tiwonge	F	Malawi	MSc	April 2017	Food Science	Baseline evaluation of peanut flour quality and processor knowledge of aflatoxin	Agnes Mwangwela	Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Emmanuel Zuza, Jr.	M	Malawi	MSc	November 2016	Crop Production		Rick Brandenburg	University Eduardo Mondlane
Rita Valentim Manjonda	F	Mozambique	MS	December 2017	Agronomy	Reproductive efficiency of Valencia peanuts under terminal drought	Carl Deom	Khon Kaen University, Khon Kaen, Thailand
Maria Jacinta De Carvalho Mopecane	F	Mozambique	MS	December 2017	Agronomy	Reproductive efficiency of Valencia peanuts under terminal drought	Carl Deom	Khon Kaen University, Khon Kaen, Thailand
Salva Samegque Inacio	F	Mozambique	MSc	July 2018	Plant Breeding	Performance of high oleic acid breeding lines		Lilongwe University of Agriculture and Natural Resources, Lilongwe, Malawi
Deok Han	M	South Korea	PhD	May 2016	Electrical Engineering	Hyperspectral and multispectral imaging, remote sensing	Haibo Yao	Mississippi State University/Stennis Space Center

Name	Gender	Home Country	Degree	Graduation Date	Discipline	Research Focus	Mentor	Training Institution
Imana Power	F	Suriname	PhD	December 2014- November 2016	Plant Pathology	Research on RNA interference	Renee Arias	University of Georgia, USA
Eric Simning	M	Tanzania	MSc		Economics	Research Technician working on the productivity effects of improved groundnut seed varieties	Boris Bravo-Ureta	
Yen Tswen Lai	F	Taiwan	MPS	May 2017	Animal Science		Dan Brown	Cornell University
Neha Paliwal		Uganda	MSc		Economics	Research technician working on the productivity effects of improved groundnut seed varieties	Boris Bravo-Ureta	
John Yawe	M	Uganda	MSc	May 2017	Agriculture Engineering/ Post-Harvest Processing	Assessment of existing drying and storage systems for peanuts	Mkandawire/ Simate / R. Brandenburg	University of Zambia
Jennifer Chagoya	F	USA	MS	December 2016	Crop Science	Breeding for tolerance to drought stress	Carl Deom	Texas Tech University
Kathryn Churchill	F	USA	PhD	December 2017	Animal Science		Dan Brown	Cornell University
Abraham Fulmer	M	USA	PhD	August 2017	Plant pathology	Leaf spots in peanut	Bob Kemerait	University of Georgia, Tifton, GA, USA
Chandler Maddox	F	USA	MS	May 2021	Plant Breeding, Genetics and Genomics	Peanut interspecific hybrids for introgression of pest and disease resistance	Peggy Ozias-Akins	University of Georgia, Tifton, GA USA
John M. North	M	USA	MS	December 2017	Agriculture Economics		Genti Kostandini	University of Georgia
LaSindia Powell	F	USA	BS	June 2016	Forensic Science	DNA extraction, analysis by fingerprinting of Aspergillus DNA	Renee Arias	Albany State University, USA
Amanda Seawright	F	USA	MSc	May 2016	Environmental Science	Aflatoxin detections in peanuts and grains	Jia-Sheng Wang	University of Georgia, Athens, GA USA

Name	Gender	Home Country	Degree	Graduation Date	Discipline	Research Focus	Mentor	Training Institution
Monica Wang	F	USA	BS	June 2015	Chemistry/Biology	Bioinformatics	Renee Arias	Emory University, USA
Kathy Xue	F	USA	PhD, MPH	May 2017	Toxicology	Aflatoxin detection in dried blood samples	Jia-Sheng Wang	University of Georgia, Athens, GA USA
Hendrix Chalwe	M	Zambia	PhD	May 2018	Agronomy	Modeling of pre-harvest aflatoxin contamination in peanuts	Alice Mweetwa/R. Brandenburg	University of Zambia, Lusaka, Zambia
Abigail Hamiwe	F	Zambia	MSc	July 2017	Biological Sciences-Molecular Biology	Microbiological contamination of peanut butters/Fungal and aflatoxin changes in Peanut Butters made from 2 varieties from Zambia	Nyambe Mkandawire, John Shindano	University of Zambia Lusaka, Zambia
Gaspard Kwizera	M	Zambia	MSc	July 2017	Human Nutrition/Post Harvest Processing	Peanut processing at the household level	Nyambe Mkandawire, John Shindano	University of Zambia Lusaka, Zambia
Lutangu Makweti	M	Zambia	MSc	November 2017	Plant Breeding		Carl Deom	
Tambudzai Makwelele	F	Zambia	BSc	October 2017	Food Science & Technology	Physio-chemical Properties and Sensory Evaluation of Peanut Butter made from three Zambian Groundnut Varieties	John Shindano/Nyambe Lisulo Mkandawire/Koushik Adhikari/R. Brandenburg	University of Zambia Lusaka, Zambia
Munsanda Ngulube	F	Zambia	MSc	October 2017	Agronomy	Use of biochar and gypsum to reduce aflatoxin in peanuts	Alice Mweetwa/R. Brandenburg	University of Zambia, Lusaka, Zambia

Non – Degree Long-Term Training (by country)

Name	Gender	Home Country	Training Institution	Dates	Discipline	Research Focus	Mentor	Training Location
Dr. Paola Faustinelli	F	Argentina	University of Cordoba, Argentina	March 2015-October 2017	Post Doc/Plant Biotechnology	RNA interference and genetic diversity of Aspergillus	Renee Arias	Texas A&M Agrilife Research
Dr. Imana Power	F	Suriname	University of Georgia, USA	December 2014-November 2016	Post Doc/Plant Pathology	RNA interference	Renee Arias	University of Georgia, Griffin, GA USA
Dr. Raphael Colbert	M	USA		2017		Peanut Crossing and breeding Techniques	Barry Tillman	

Workshops and Courses

Event	M	F	Trainee(s)	Dates	Trainer/Institution	Research Focus	Mentor	Training Location
APRES 2017	0	5		07/11/17-07/13/2017			Agnes Mwangwela	Albuquerque, NM
CLC-Bio-Software	5	3		05/17/2016	Monica Wang	Training Bioinformatics	Renee Arias	Dawson, GA
Stakeholder Workshop	11	24	Extension staff, Research Technicians	December 14-18, 2018	Justus Chintu, Donald Siyeni/DARS, Malawi	Groundnut Trials and Demostrations	Carl Deom	Salima, Malawi
Training of Extension staff and Technicians	19	11	Extension staff and Research Technicians	April 18-22, 2016	Justus Chintu, Donald Siyeni/DARS,Malawi	Trial Management, Groundnut Production	Carl Deom	Salima, Malawi
Field Days	52	98	Farmers	April 2016	Justus Chintu	New Groundnut Varieties, PVS, Production practices for high productivity	Carl Deom	Ntcheu, Lilongwe, and Karonga, Malawi
Plot Harvesting	12	16		November 2015	Students and Women	Harvesting	Carl Deom	Gampela and POBE, Burkina Faso
Field Monitoring	12	10		July 30, 2016 to harvesting time	M. Almissa, Students and Farmers	Plot Notes	Carl Deom	Gampela and POBE, Burkina Faso
Field monitoring	8	20		Aug 29, 2016	P. Sankara	Planting and Field Plot Design	Carl Deom	Gampela, Burkina Faso
	46	24	World Vision-Mbale Butaleja cluster	March 2016	D.K. Okello and P. Osia,/ NASRRI	Groundnut Production System	Carl Deom	Uganda
	33	28	World Vision Sorotu cluster	February 2016	D.K. Okello and P. Osia/ NASRRI	Groundnut Production System	Carl Deom	Uganda
	10	7	Technicians East and Southern Africa	May 2016	D.K. Okello/ NASRRI	Legume Breeding Systems	Carl Deom	East and Central African
	9	4	Students Interns(certificate, Diploma, Bachelors	May 2- July 30, 2016	D.K. Okello/ NASRRI	Groundnut Value Chain	Carl Deom	Uganda
	11	16	Danish Refugee Council-Amuria	May 2016	D.K. Okleeo, P.Anguria, and P. Osia/NASRRI	Seed Systems, Agronomy	Carl Deom	Uganda
	32	38	ZOA Amuru	June 2016	P. Osia and S. Ocuga/NASRRI	Seed Systems, Agronomy, Crop Protection	Carl Deom	Uganda
	14	18	LSB Dokolo	June 2016	D.K. Okello and P. Anguria/NASRRI	Seed Systems	Carl Deom	Uganda

Event	M	F	Trainee(s)	Dates	Trainer/Institution	Research Focus	Mentor	Training Location
ZOA Farmer Training	73	48	Farmers	August 24, 2016	P. Osia and S. Ocuga/NASRRI	Seed Systems and Crop Protections	Carl Deom	Uganda
	25	7	Haitian Peanut Research Agronomist	June 21, 2016	/MFK & PMIL	Experimental Design and best management practices	Greg MacDonald	Quartier-Morin, Haiti
Enumerator Workshop	6	3		June 3, 2016, June 6-8, 2016	Boris Bravo-Ureta, Jermy Jelliffe	Familiarize enumerators with the survey instrument	Boris Bravo-Ureta	Nampula, Mozambique
Aflatoxin Training	9	16	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Digbila Village, Northern Region, Ghana
Aflatoxin Training	17	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Geluwei Village, Northern Region, Ghana
Aflatoxin Training	16	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Kpsinga Village, Northern Region, Ghana
Aflatoxin Training	17	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Nyong Village, Northern Region, Ghana
Aflatoxin Training	17	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Tamalegu Village, Northern Region, Ghana
Aflatoxin Training	17	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Kplung Village, Northern Region, Ghana
Aflatoxin Training	17	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Nyeko Village, Northern Region, Ghana
Aflatoxin Training	17	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Ying Village, Northern Region, Ghana
Aflatoxin Training	17	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Zion Village, Northern Region, Ghana
Aflatoxin Training	17	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Zoggu Village, Northern Region, Ghana

Event	M	F	Trainee(s)	Dates	Trainer/Institution	Research Focus	Mentor	Training Location
Aflatoxin Training	14	7	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Gbrimani Village, Northern Region, Ghana
Aflatoxin Training	17	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Kpakyiyli Village, Northern Region, Ghana
Aflatoxin Training	16	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Kpaliga Village, Northern Region, Ghana
Aflatoxin Training	17	8	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Satani Village, Northern Region, Ghana
Aflatoxin Training	17	9	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Yipelgu Village, Northern Region, Ghana
Aflatoxin Training	16	9	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Bachalbado Village, Northern Region, Ghana
Aflatoxin Training	17	9	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Macheliyili Village, Northern Region, Ghana
Aflatoxin Training	16	9	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Naaduno Village, Northern Region, Ghana
Aflatoxin Training	16	9	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Sambu Village, Northern Region, Ghana
Aflatoxin Training	16	9	Farmers	August/September 2015	Abdulai Baako/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Tijo Village, Northern Region, Ghana
Aflatoxin Training	16	9	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Achobisi Kasam Village, UE Region, Ghana
Aflatoxin Training	16	9	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Asibiga Village, UE Region, Ghana

Event	M	F	Trainee(s)	Dates	Trainer/Institution	Research Focus	Mentor	Training Location
Aflatoxin Training	16	9	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Balungu-Gantorisi Village, UE Region, Ghana
Aflatoxin Training	16	9	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Basiengo-Amenabisi Village, UE Region, Ghana
Aflatoxin Training	16	9	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Beo Kasingo Daporyorogo Village, UE Region, Ghana
Aflatoxin Training	16	9	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Bonia Village, UE Region, Ghana
Aflatoxin Training	18	9	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Chuchuliga Tiedema Village, UE Region, Ghana
Aflatoxin Training	18	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Chuchulia Yipaala Village, UE Region, Ghana
Aflatoxin Training	18	9	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Chuchulia Adabinsa Village, UE Region, Ghana
Aflatoxin Training	18	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Chuchulia Akpoteyera Village, UE Region, Ghana
Aflatoxin Training	17	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Dulugu Aginbisi Village, UE Region, Ghana

Event	M	F	Trainee(s)	Dates	Trainer/Institution	Research Focus	Mentor	Training Location
Aflatoxin Training	18	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Dulugu-Asanorebisi Village, UE Region, Ghana
Aflatoxin Training	17	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Feo Asimabisi Village, UE Region, Ghana
Aflatoxin Training	17	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Nyangua Village, UE Region, Ghana
Aflatoxin Training	16	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Sumbrungu Kologo Akanyebi Village, UE Region, Ghana
Aflatoxin Training	17	9	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Sumbrungu Yeobongo Nayire Village, UE Region, Ghana
Aflatoxin Training	17	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Tampola Village, UE Region, Ghana
Aflatoxin Training	17	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Vea Gunga Village, UE Region, Ghana
Aflatoxin Training	18	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Wiaga Yemonsa Village, UE Region, Ghana
Aflatoxin Training	18	8	Farmers	September/October 2016	Joseph Amenini and Thomas Anobiga/MoA, Noah Saduli/UDS, Vincent Ninkuu/UDS	Train treatment farmers on post-harvest best practices	Nick Magnan	Yikene Village, UE Region, Ghana
Workshop/Symposium	60	70	Professionals	November 28-December 1 2016		Introduce DBS method	JS Wang	Hangzhou, China

Event	M	F	Trainee(s)	Dates	Trainer/Institution	Research Focus	Mentor	Training Location
Course Module	33	9		Fall 2015	Nelson Opoku/UDS	Practical training in aflatoxin analysis	Nick Magnan	Ghana
Course Module	3	10		Fall 2016	Nelson Opoku/UDS	Practical training in aflatoxin analysis	Nick Magnan	Ghana
NARO meeting	2	0		September 19-22, 2016	David Okello	NARO Groundnut program	Boris Bravo-Ureta	Kampala, UG & Soroti, UG
Forecasting	3	1		2017	/ISSD:NARO	Seed demand forecasting	Carl Deom	Uganda
Breeding	3	0		2017	/ICRISAT:TLIII	Breeding Management Systems	Carl Deom	Uganda
Improvement	1	1		2017	/ICRISAT:TLIII	Gender in Groundnut Improvement	Carl Deom	Kenya
Breeding	2	0		2017	/ICRISAT	Breeding Management Systems	Carl Deom	Kenya
Production	10	10	Ag professionals	2017		Exposed Ag Professional s wotking in peanuts to modern production practices	Carl Deom	Haiti
Seed Quality	77	23	Para seed inspectors	2017		New attributes of newly released groundnuts	Carl Deom	Malawi
Prevention	660	339	Farmers	2017		Aflatoxin prevention refresher course	Nicholas Magnan	Ghana
Prevention	10	0	Student enumerators	2017		Training on delivering the aflatoxin prevention refresher course	Nicholas Magnan	Ghana
Prevention	13	12	Field Staff and Farmers	2017		Aflatoxin Prevention (using video)	Nicholas Magnan	Ghana
Aflatoxin Testing	70	70	3rd and 4th year students at UDS	2017		Practical aflatoxin testing and analysis	Nicholas Magnan	Ghana
Training	0	5	Nurses	2013-2017		3 times each year in anthropometry, data collection and management, and nutritional education	Mark Manary	Malawi
Workshop/Symposium	60	60	Professionals	June 2017		Introduce DBS method	JS Wang	Wuxi, China
Annual Meeting	50	50	Professionals	March 2017		Introduce DBS method and results	JS Wang	Baltimore, Maryland

Program Partners

United States of America

Institution	Department	City	State
Auburn University	Department of Agronomy & Soils	Auburn	AL
California Polytechnic State University	Food Science and Nutrition	San Luis Obispo	CA
University of Connecticut	Agricultural and Resource Economics	Storrs	CT
IMPAQ International		Columbia	MD
International Food Policy Research Institute (IFPRI)		Washington	DC
University of Florida	Agronomy Department	Gainesville	FL
Premier Steppe Ferme		Lake Worth	FL
University of Florida	North Florida Research and Education Center	Marianna	FL
Frank's Designs for Peanuts, LLC		Mexico Beach	FL
University of Georgia	Center for Applied Genetic Technologies	Athens	GA
University of Georgia	Department of Plant Pathology	Athens	GA
University of Georgia	Center for Applied Genetic Technologies	Athens	GA
University of Georgia	Department of Agricultural and Applied Economics	Athens	GA
University of Georgia	Department of Environmental Health Science	Athens	GA
United States Department of Agriculture-Agriculture Research Service (USDA-ARS)	National Peanut Research Laboratory	Dawson	GA
United States Department of Agriculture-Agriculture Research Service (USDA-ARS)	Plant Genetic Resources Conservation Unit	Griffin	GA
University of Georgia	Department of Food Science and Technology	Griffin	GA
United States Department of Agriculture-Agriculture Research Service (USDA-ARS)	Coastal Plain Experiment Station	Tifton	GA
University of Georgia	Plant Pathology	Tifton	GA
University of Georgia	Department of Plant Pathology	Tifton	GA
University of Georgia	National Environmentally Sound Production Agriculture Laboratory (NESPAL)	Tifton	GA
University of Georgia	Department of Entomology	Tifton	GA
United States Department of Agriculture-Agriculture Research Service (USDA-ARS)	Food and Feed Safety Research	New Orleans	LA
Tufts University	School of Nutrition Science and Policy	Boston	MA
Meds & Food for Kids		St Louis	MO
Washington University School of Medicine	College of Medicine	St. Louis	MO

Institution	Department	City	State
Mississippi State University	Geosystems Research Institute	Stennis Space Center	MS
United States Department of Agriculture - Agriculture Research Service (USDA-ARS)	Genomics & Bioinformatics Research Unit	Stonesville	MS
North Carolina State University	Department of Entomology	Raleigh	NC
North Carolina State University	Department of Crop Science	Raleigh	NC
New Mexico Sate University	Agricultural Science Center	Clovis	NM
Cornell University	Animal Science	Ithaca	NY
Texas A&M University	Lubbock Research & Extension Center	Lubbock	TX
Texas A&M University	AgriLife Research	Stephenville	TX
Virginia Polytechnic Institute and State University	Biological Systems Engineering	Blacksburg	VA
Virginia Polytechnic Institute and State University	Tidewater Agricultural Research & Extension Center	Suffolk	VA

Foreign

Institution	Department	City
Burkina Faso		
University of Ouagadougou	Departement de Phytopathologie	Quagadougou
Ghana		
Counsel for Scientific and Industrial Research (CSIR)	Crops Research Institute (CRI)	Kumasi
Kwame Nkrumah University of Science and Technology (KNUST)	Department of Crop and Soil Sciences	Kumasi
Kwame Nkrumah University of Science and Technology (KNUST)	Food Science and Biotechnology	Kumasi
University of Ghana	Institute of Statistical, Social, and Economic Research	Legon
University of Ghana	Department of Nutrition and Food Science	Legon
Counsel for Scientific and Industrial Research (CSIR)	University for Development Studies	Tamale
Counsel for Scientific and Industrial Research (CSIR)	Savanna Agricultural Research Institute (SARI)	Wa
Haiti		
TechnoServe		Petionville
Meds & Food for Kids		Quartier Morin
Partners in Health/Zanmi Agrikol		Corporant
Acceso Peanut Enterprise Corporation		Petionville
India		
Tamil Nadu Agricultural University	Department of Plant Biotechnology	Chennai
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	Grain Legumes Research Program	Hyderabad

Institution	Department	City
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	Center of Excellence in Genomics	Hyderabad
Kenya		
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	East and Southern Africa Regional Program	Nairobi
Kenyatta University	Plant Transformation Lab	Nairobi
Malawi		
University of Malawi	College of Medicine	Blantyre
Afri-Nut		Lilongwe
Lilongwe University of Agriculture and Natural Resources	Department of Home Economics & Human Nutrition	Lilongwe
Chitedze Agriculture Research Service		Lilongwe
Exagris Africa Ltd.		Lilongwe
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	Chitedze Agricultural Research Station	Lilongwe
National Smallholder Farmers Association of Malawi (NASFAM)		Lilongwe
Mali		
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	West and Central Africa Regional Program	Bamako
Mozambique		
Edwardo Mondlane University		Maputo
Instituto de investigação Agrária de Moçambique (IIAM)		Maputo
IKURU Farmer's Cooperative		Nampula
Lurio University		Nampula
Mozambique Agricultural Research Institute	Northeast Zonal Center	Nampula
Nigeria		
International Institute of Tropical Agriculture (IITA)		Ibadan
Senegal		
Institut Senegalais de Researches Agricoles (ISRA)	Centre National de Recherches Agronomiques (CNRA)	Bambey
Institut Senegalais de Researches Agricoles (ISRA)	Centre d'etude regional pour l'amelioration de l'adaptation a la secheresse (CERAAS)	Thies
Uganda		
National Agricultural Research Organization (NARO)	National Crops Resources Research Institute (NaCRRI)	Kampala
National Agricultural Research Organization (NARO)	Savanna Agricultural Research Institute (SARI)	Nyankpala
National Agricultural Research Organization (NARO)	National Semi Arid Resources Research Institute (NaSARRI)	Soroti
Bulogo Women's Group		
Zambia		
Eastern Province Farmer's Cooperative Ltd.	Katopola Farm Institute	Chipata
Zambia Agriculture Research Institute (ZARI)		Chipata
Zambia Agriculture Research Institute (ZARI)	Mt. Makulu Central Research Station	Lusaka
University of Zambia	School of Agricultural Sciences	Lusaka

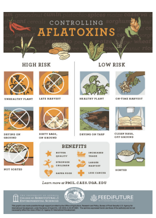
Graphics and Resources

The Management Entity and individual collaborators created several guides, infographics and videos to make research findings accessible to the people who could use the information.

[Impactful Peanuts](#)
Every part of the peanut has a use for the household, from cooking oil to extra income to plant rotation.
[Chichewa](#), [Creole](#), [French](#), [Luo](#), [Oromo](#), [Portuguese](#), [Spanish](#), [Twi](#)

[Detecting Mycotoxins](#)
Because mycotoxin contamination doesn't spread evenly, finding the one contaminated nut or kernel – while preserving the clean nuts or kernels – is difficult. Following established sampling procedure helps.
[English](#), [French](#), [Spanish](#)

[One Handful](#)
Just a handful of peanuts have as much protein as a chicken leg or two glasses of milk.
[Ateso](#), [Chewa](#), [Chichewa](#), [Creole](#), [French](#), [Dagbani](#), [Luganda](#), [Lugbara](#), [Luo](#), [Oromo](#), [Portuguese](#), [Runyankole](#), [Spanish (Guatemala)](#), [Spanish (Honduras)](#), [Twi](#)



[Controlling Aflatoxin](#)
Simple, but proven actions can discourage the build-up of aflatoxin and benefit the farmer financially.
[Ateso](#), [Chewa](#), [Creole](#), [Dagbani](#), [French](#), [Luganda](#), [Luo](#), [Oromo](#), [Runyankole](#), [Twi](#)

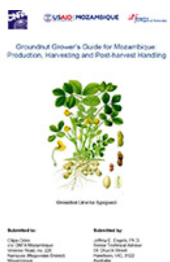
[Groundnut Seed Production Guidelines (Zambia)](#)
This trifold brochure covers varieties, recommended farming practices and proper storage to avoid aflatoxin contamination, while helping the farmer recognize the most common peanut diseases in the area.
[Chewa](#)

[Groundnut Leaf Miner (Uganda)](#)

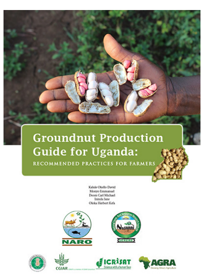
Integrated Practices to Manage Diseases, Nematodes, Weeds and Arthropod Pests of Groundnut in Ghana

This 100-page manual helps farmers from site selection to planting to pest management to shelling and storage.

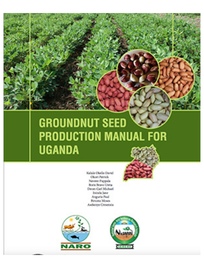
Groundnut production from planting to harvest (Ghana)
This trifold brochure covers planting, growing and harvesting. A graphic explains how to decide the optimum day to harvest and the cost of harvesting too early or too late.
Dagbani, Twi



Groundnut Grower's Guide for Mozambique: Production, Harvesting and Post-harvest Handling
This 58-page book covers peanut production in Mozambique from choosing the right variety to storing properly.



Groundnut Production Guide for Uganda: Recommended practices for Farmers
This 42-page book was published by the National Agricultural Research Organisation in collaboration with Makerere University.



Groundnut Seed Production Manual for Uganda
The National Agricultural Research Organisation Entebbe in Uganda published this guide in 2015.

This Final Report (covering the years 2012 to 2017) is a publication of the Feed the Future Innovation Lab for Collaborative Research on Peanut Productivity and Mycotoxin Control.

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FEED THE FUTURE PEANUT & MYCOTOXIN INNOVATION LAB