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

Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet

Annual Performance Report FY 2018

October 1, 2017 – September 30, 2018

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FEED THE FUTURE INNOVATION LAB
Collaborative Research on Sorghum and Millet

KANSAS STATE UNIVERSITY

Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet
Annual Performance Report FY 2018

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Cover photo:
A woman prepares millet couscous in her home in Dakar, Senegal.
Photo credit: Kira Everhart-Valentin

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Management entity information

The core management entity team again did not see any changes in staffing this year, thus maintaining the same program staff members as follows:

1) Timothy J. Dalton – *Director*
2) Nathanael Bascom – *Assistant Director*
3) Kira Everhart-Valentin – *Program Coordinator*
4) Kimberly Suther – *Fiscal Analyst*

In addition to the core management team, Melissa Jagger was hired on contract to provide technical and scientific writing services in relation to the Lab's gender and sorghum production in Ethiopia report. That contract ended in July 2018.

The management entity's in-country coordination team has remained stable, with the current team as follows:

1) Senegal - Ndiaga Cisse
2) Soumana Souley – Niger (supported by previous coordinator, Moustapha Moussa)
3) Getachew Ayana – Ethiopia

The Lab's management entity also continues to support agricultural economics Ph.D. student Tebila Nakelse during his program of study and associated contributions to the Lab's market research in West Africa as well as Mengistu Kassie, a Master's student from Ethiopia in agricultural economics. Both are at Kansas State University – Nakelse is set to complete his program of study in December 2018 and Kassie will complete his in May 2019.

Dr. Desalegn Serba, a Kansas State University pearl millet breeder supported by the Sorghum and Millet Innovation lab, continues to make progress in his evaluation of pearl millet lines for stress tolerance and yield potential. He has been active in building relationships with the Lab's West African breeding teams and is establishing priorities that will continue to shape his future research and contribute to varietal development in the region.

External Advisory Board information

Since the Lab's inception, the External Advisory Board (EAB) has played a key role in ensuring that the Lab's research and management practices are both high-quality as well as relevant. The EAB members have remained consistent throughout the life of the Lab, and include:

1) Dr. Brhane Gebrekidan - *Ethiopian Academy of Sciences*
2) Prof. Bettina Haussmann - *University of Hohenheim, also serving as West Africa Liaison Scientist for the McKnight Foundation and Capacity Development Manager at the KWS SAAT SE*
3) Tim Lust - *Chief Executive Officer of the National Sorghum Producers*
4) Dr. Peter Matlon - *Adjunct Professor at Cornell University*
5) Prof. Barbara Stoecker - *Regents Professor and Marilynn Thomas Chair at Oklahoma State University*

In FY 2018, the EAB came together with global sorghum community at the *Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World* and at the Sorghum and Millet Innovation Lab program-wide meeting that took place immediately following the global conference. EAB member Bettina Haussmann also took part at the West Africa Regional Pearl Millet Convening in September as an active presenter, facilitator and advisor. Additionally, the EAB was called upon as a key participant in the Lab external evaluation that was commissioned by USAID.

As in previous years, the management entity continued to provide periodic updates on activities and research-related developments to the EAB throughout the year, as well as consult them for guidance when areas of challenge arose.

Bettina Haussmann's plenary session presentation at the Sorghum in the 21st Century global sorghum conference, titled "Tackling key issues for smallholder farmers: The farmer research network approach," was well received and generated a more holistic thinking as regards to agro ecological intensification and farmer research networks across the conference topical and symposium sessions.

Focus countries

The Lab continues to work primarily in its focus countries – Ethiopia, Senegal and Niger – and secondarily in Burkina Faso, Mali and Haiti. Activities in Haiti are supported through an associate award initiated in FY 2016.

List of program partners

United States

Cornell University
Integrated Pest Management Innovation Lab
Kansas State University
Kansas State University – Western Kansas Agricultural Research Center, Hays
Purdue University
Texas A&M AgriLife Research
Texas A&M University
USDA-Agricultural Research Service
Virginia Tech University
West Texas A&M University

Ethiopia

Ethiopian Institute of Agricultural Research
- *Asosa Research Center*
- *Jimma Research Center*
- *Melkassa Research Center*
- *Pawe Research Center*
- *Sirinka Research Center*

Haramaya University
Hawassa University
Holleta Biotechnology Center
Oromia Agricultural Research Institute
- *Bako Research Center*

Tigray Agricultural Research Institute
Tigray Regional Program

Senegal

Centre d'Etudes Régional pour l'Amélioration de l'Adaptation à la Sécheresse
Centre National de Recherche Agronomique
FAPAL (farmer organization)
Institut Sénégalais de Recherches Agricoles
Institut de Technologie Alimentaire
University Cheikh Anta Diop de Dakar

Niger

Fuma Gaskiya (farmer organization)
HALAL (farmer organization)
Institut National de la Recherche Agronomique du Niger
International Crops Research Institute for the Semi-Arid Tropics
LSDS (farmer organization)
University of Maradi

Mali

Institut d'Economie Rurale

Burkina Faso

Institut de l'Environnement et de Recherches Agricoles

Haiti

CHIBAS
Quisqueya University

Germany

University of Hohenheim

France

Centre de Coopération Internationale en Recherche Agronomique pour le Développement

Republic of South Africa

University of Pretoria

Acronyms

ARS	Agricultural Research Service
BMR	Brown Midrib
CERAAS	Centre d'Etude Régional pour l'Amélioration de l'Adaptation à la Sécheresse
CGIAR	Consultative Group on International Agricultural Research
CHIBAS	Centre de Recherche sur les Biocarburants et l'Agriculture Durable
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CNRA	Centre National de Recherche Agronomique
EAB	External Advisory Board
EIAR	Ethiopian Institute of Agricultural Research
EMMP	Environmental Mitigation and Monitoring Planning
EMS	Ethyl Methanesulfonate
DNA	Deoxyribonucleic Acid
GBS	Genotyping-by-sequencing
HX	Heterowaxy
HPD	High Protein Digestibility
ICRISAT	International Crops Research Institute for the Semiarid Tropics
IDIN	International Disease and Insect Nursery
IDLT	International Drought Line Test
IER	Institut d'Economie Rurale
INERA	Institut de l'Environnement et de Recherches Agricoles
INRAN	Institut National de Recherches Agronomiques du Niger
IPM	Integrated Pest Management
ISRA	l'Institut Sénégalais de Recherches Agricole
ITA	Institut de Téchnologie Alimentaire
KSU	Kansas State University
KDA	Kansas Department of Agriculture
ME	Management Entity
MHM	Millet Head Miner
MLT	Midge Line Test
MSB	Millet Stem Borer
NAM	Nested Association Mapping
NARI	National Agricultural Research Institutes
NSP	National Sorghum Producers
OSU	Oklahoma State University
PI	Principal Investigator
PMP	Performance Monitoring Plan
RFA	Request for Application
SICNA	Sorghum Improvement Conference of North America
SIIL	Sustainable Intensification Innovation Lab
SME	Small Medium Enterprises
SMIL	Sorghum and Millet Innovation Lab
SNP	Single Nucleotide Polymorphism
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WAAPP	West Africa Agricultural Productivity Program
WACCI	West African Centre for Crop Improvement
WX	Waxy

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Executive summary

The five-year phase of the Sorghum and Millet Innovation Lab (SMIL) began on July 23, 2013 and concluded on July 22, 2018 but follows a thirty-four year history of the INTSORMIL program under the Collaborative Research Support Program (CRSP) mechanism. Kansas State University hosts the Sorghum and Millet Innovation Lab in the College of Agriculture. The program administers a "Leader with Associates" Cooperative agreement with substantive involvement by USAID. The primary goal of the management entity is to develop a portfolio of research activities, combined with human and institutional capacity development, to improve the functioning of the sorghum and millet value chains in target countries. An external advisory board serves a managerial role in the selection, overview and evaluation of projects and advice on programmatic management.

The Sorghum and Millet Innovation Lab funded twelve research projects that were selected through a competitive process: four in Ethiopia and eight targeting West Africa. Seven projects focus on genetic enhancement of sorghum or pearl millet, two on production systems management and two on added-value product development and markets. One project cuts across genetic enhancement and production systems management. Several technological innovations were developed that are being scaled while the breeding programs have generated intermediate innovations.

The Sorghum and Millet Innovation Lab completed its fifth year by either fully, or partially, funding 68 long-term students. Four of these students received prestigious awards for their accomplishments including the BIFAD award for student excellence. Short-term trainings reached more participants than originally anticipated. These trainees included producers, civil society members (predominantly researchers and students), government representatives and individuals from private sector firms. Producers made up the largest portion of those trained through the Sorghum and Millet Innovation Lab activities. Across the five-year period of the Lab's first phase, approximately 9,750 individuals were trained.

In pursuit of our programmatic objective to build a coalition of science and industry around sorghum and millet where structure and opportunity creates entrepreneurial advances to reduce poverty and hunger, SMIL co-hosted, in collaboration with the University of Pretoria, the first global sorghum conference of this century and the first in over twenty-five years. Held from April 9-12, 2018 in Cape Town, South Africa, the conference drew over 400 participants from 40 countries comprised of researchers, industry professionals, government representatives and development specialists around a broad variety of sorghum-related topics, including food security, value-added products, genetics, global trade, climate-smart agriculture. In addition, a parallel, but smaller, convening was held on pearl millet. Nearly 90 researchers and stakeholders from across the West Africa pearl millet value chain came together at a regional convening co-hosted by the Sorghum and Millet Innovation Lab on September 4-6, 2018 in Thies, Senegal. Targeted at major actors in pearl millet from Senegal, Niger, Mali and Burkina Faso, the *2018 West Africa Regional Pearl Millet Convening* was also co-hosted by the Centre d'Etude Régional pour l'Amélioration de l'Adaptation à la Sécheresse (CERAAS), and the USDA sponsored NCBA CLUSA Millet Business Services Project. A final report on the first five-year phase is available at: http://www.k-state.edu/smil/about/reports/index.html.

Program activities and highlights

The Sorghum and Millet Innovation Lab completed its five-year program (July 2013-July 2018) during this fiscal year and committed no-cost extensions to projects in order to complete the cropping year in Ethiopia and West Africa. The SMIL research program portfolio is delivering technology packages to the marketplace and is generating intermediate outputs to improve the efficiency of long-term breeding programs. At present, the SMIL program has numerous technologies in process in phase I (*Under research*), II (*Under field-testing*), III (*Available for scaling*), IV (*Actively being scaled*) with other technologies that will continue to develop. Phase III technology packages that are now available for scaling include:

- Registered sorghum germplasm with resistance against the sugarcane aphid for utilization by global breeding teams.
- A white sorghum hybrid with strong yield performance for uptake in lowland production areas of Ethiopia.
- Seed ball formulation, production, and planting techniques to reduce risk and improve yield for pearl millet farmers in the Sahelian zone of West Africa.
- An integrated pest management technology with mass rearing of naturally occurring beneficial parasitoid wasps and timely release at a community level to control the millet head miner in West Africa.

The Sorghum and Millet Innovation Lab funded, either fully or partially, 68 long-term students. Four of these students received prestigious awards for their accomplishments including the BIFAD award for student excellence. Short-term trainings reached more participants than originally anticipated. These trainees included producers, civil society members (predominantly researchers and students), government representatives and individuals from private sector firms. Producers made up the largest portion of those trained through the Sorghum and Millet Innovation Lab activities. Across the five-year period of the Lab's first phase, approximately 9,750 individuals were trained.

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Key accomplishments

FY 2018 witnessed the culmination of efforts from the past five years in a number of accomplishments that directly contribute to established objectives (*see Theory of change and impact pathways, pg. 5*). These centered on building target country capacity for the creation and dissemination of innovations aligned with national plans and contexts. This was achieved through continued efforts to develop technology packages plus a strong focus on human and institutional capacity development of national partners, thereby contributing to the Lab's three objectives around the building of a coalition of science and industry, the incubation of a new wave of feed and food products and the creation of a business and research investment plan that leverages funding and support for maximum impact.

Capacity building occurred on a number of levels, including institutional support, individual scientist training and associated enhancement of research programs, development of a global sorghum network via the *Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World*, and the planning of a West Africa regional pearl millet network through a convening in early September at the *Centre d'Etude Régional pour l'Amélioration de l'Adaptation à la Sécheresse* (CERAAS) in Thiès, Senegal. The success of some of these capacity building activities was witnessed through the recognition of several of the program's long-term trainees for their research and related accomplishments, including the receipt of the *BIFAD Award of Excellence for Student Research* by Mr. Amadou Laouali.

Additionally, the Lab supported a total of 68 trainees, six of which are new to the program's roster this year. Among those 68 trainees, 46 are male and 22 are female. The group also represents a variety of degree levels with two agricultural engineers, five Bachelor's, 30 Master's, 30 Ph.Ds. and one post-doc.

In FY 2018, the Lab again surpassed the anticipated target number of short-term trainees by more than 700 individuals. Across all projects, the Lab trained a total of 2,081 individuals, including 708 males and 1,373 females. Producers made up the largest group with 1,685 trained, followed by 204 civil society members (predominantly researchers and students), 88 people in government, 22 in private sector firms and 82 unknown.

Four technology packages have moved into a *Phase III* of research, making them ready to begin the scaling process. These include:

- Registered sorghum germplasm with resistance against the sugarcane aphid for utilization by global breeding teams.
- A white sorghum hybrid with strong yield performance for uptake in lowland production areas of Ethiopia.
- Seed ball formulation, production, and planting techniques to reduce risk and improve yield for pearl millet farmers in the Sahelian zone of West Africa.
- An integrated pest management technology with mass rearing of naturally occurring beneficial parasitoid wasps and timely release at a community level to control the millet head miner in West Africa.

A technology catalog is currently under development to help link government actors, NGOs and end users to these technologies for adoption. The catalog will be available on the Lab website, and the technologies will also be listed with USAID's online marketplace to increase overall accessibility to innovations.

Research program overview and structure

The Sorghum and Millet Innovation Lab's research program continues on its established course with a few changes that are responsive to program evolution. The program currently has twelve projects, funding commitments to 24 institutions and these institutions are responsible for pass-through agreements to approximately 25 additional organizations. Projects are led by several institutions including Purdue University (four projects), Kansas State University (three projects), Texas A&M, West Texas A&M, ICRISAT and the University of Hohenheim (one project each). The pearl millet improvement project is being led by the Burkina Faso national agriculture research program (INERA) and integrates researchers from Mali, Niger and Senegal. These projects are associated with 18 collaborating institutions in West Africa and another 16 collaborating institutions in Ethiopia, as well as one collaborating institution in France. During this year, the program initiated a new associate award project to develop a genomics assisted breeding program in Haiti that drew in two new institutions - CHIBAS, in Haiti, and Cornell University - in addition to collaborators at Kansas State University. This project started in FY 2017 and conducted field and lab activities this year.

The program is organized around three areas of inquiry: 1) Genetic enhancement, 2) Production systems management, and 3) Market development and added-value products. Since the program is commodity focused, more than fifty percent of our projects focus on sorghum and pearl millet crop improvement with the remaining projects split between production systems management and added-value products. Geographically, slightly more than 50% of Lab financial resources for research are focused on Ethiopia and the remainder in West Africa. The Associate Award focuses only on Haiti.

Theory of change and impact pathways

The theory of change for the Sorghum and Millet Innovation Lab lies in the development of technological innovations targeted at the sorghum and millet value chains in response to national needs assessments. It is centered on the development of new varieties, crop management practices, and food processing and marketing techniques. As a commodity-based Innovation Lab, the emphasis of much of its work is in the area of technological innovation, facilitating diffusion of technology and disruptive system change in order to increase productivity and profitability at several entry points along the value chain. The following diagram illustrates this relationship:

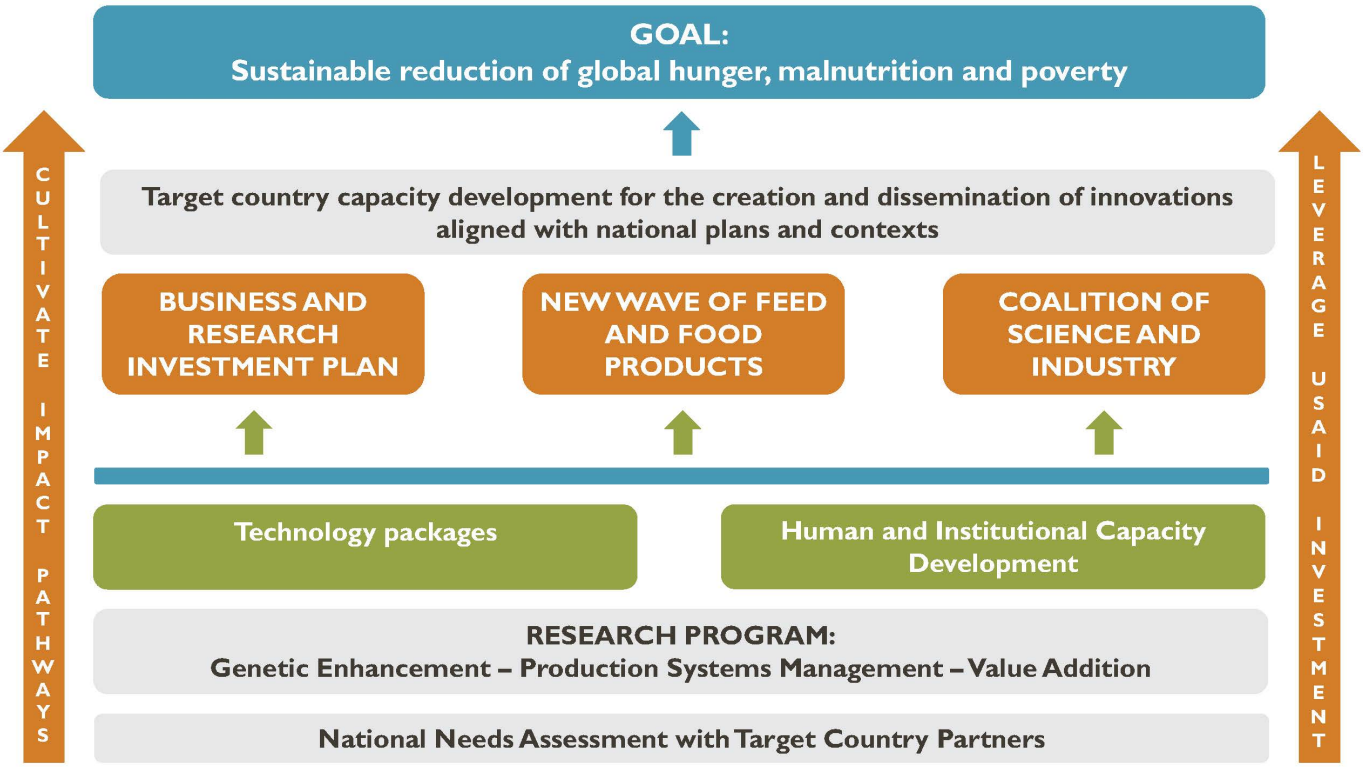


Figure 1: Sorghum and Millet Innovation Lab Theory of Change

The theory of change embedded in the Sorghum and Millet Innovation Lab's activities is based upon a "bottom's up" identification of needs and priorities derived from stakeholders along the sorghum and millet value chains. Once needs and priorities have been identified, a competitive call for proposals is used to identify the innovative strategies to address these problems.

Specific technology packages are key outputs of each proposal and the management entity will cultivate pathways to support uptake and scaling of technology packages that are at a Phase III, ready for scaling level. A technology catalog is being developed that will feature technology packages at the Phase III level. Using a scaling tool, a scaling scan per technology package will be completed to better assess the potential for scaling. This will include an assessment of areas such as technology practice, awareness/demand, business case, value chain integration, finance, knowledge/skills, collaboration networks, evidence/learning level, leadership/management, and public sector governance.

Through strategic partnerships, the Lab management entity will leverage multi-sectoral networks and collaborations as well as USAID investments to accelerate further scaling. This demand-driven approach ensures research relevance based on national needs which supports USAID's overarching aim to sustainably reduce global hunger, malnutrition and poverty.

Human and institutional capacity development is an essential component of the SMIL's theory of change. The Lab will build on the primary inputs into the innovation systems to include human capital in the form of stakeholders in product outcomes, trained and equipped research scientists, students, technicians, extensionists, technology transfer specialists; physical capital in the form of innovation centers, laboratories, farm and research station fields, other durable capital used to irrigate and cultivate fields, disposable supplies such as biochemical inputs, fuel and laboratory supplies, electricity, internet access and telephone. In addition, critical social capital found in producer groups and cooperative organizations contribute to familiarization, facilitation and adoption of technologies.

Performance Monitoring Plan and the Theory of Change

The Lab performance monitoring plan provides overarching strategies for implementing the theory of change. In summary, the Lab is contributing towards the overall goal of sustainably reducing global hunger, malnutrition and poverty through the generation of innovative technologies that will be scaled along the sorghum and millet value chains as well as long-term human and institutional capacity development in agricultural research.

The management entity is playing an enabling role to develop and capacitate global research teams that implement projects that are fully integrated into the national-level research priorities. In addition to the long-term human and institutional capacity development outputs, technology packages are being generated which will become ready for uptake and scaling. The management entity is leveraging multi-sector collaborations and USAID investment to further scale these technologies.

Three key objectives of the program stated in the performance monitoring plan play a pivotal role our theory of change:

I. *Build a coalition of science and industry around sorghum and millet where structure and opportunity can create entrepreneurial advances to reduce poverty and hunger.*

II. *Incubate and nurture a new wave of feed and food products to stimulate demand for sorghum and millet thereby extending economic benefits beyond the farmgate into the broader population.*

III. *Create an economically rationalized business and research investment plan to leverage USAID core financing and attract associate awards and broader donor support.*

The Lab's research program includes the areas of inquiry of genetic enhancement, production systems management, and value addition. Technology packages and human and institutional capacity are key outputs across these areas of inquiry.

All research projects support the key *Objective I*: *Build a coalition of science and industry around sorghum and millet where structure and opportunity can create entrepreneurial advances to reduce poverty and hunger,* which in turn is contributing to the program goal of *sustainably developing the capacity to create and disseminate innovations aligned to national plans and context*. Research projects are also contributing towards *objectives II and III* depending on their specific area of inquiry and integration of economic research.

Research project reports

AREA OF INQUIRY: Genetic enhancement

Improved crop genetics, production practices and processing methods for increased productivity and nutrition for smallholder sorghum producers in Ethiopia
(Led by Dr. Tesfaye Tesso – Kansas State University)

Additional area(s) of inquiry
Production systems management

Location (zonal level)
Ethiopia - East Shewa, North Wollo, Addis Ababa, Arsi, East Hararghe, West Gojam, South Tigray, East Tigray

Description
This project focuses on developing and utilizing high-yielding, locally-adapted sorghum varieties and hybrids that are rich in highly-digestible protein and essential micronutrients, while at the same time suiting local processing methods and diverse production systems. Through collaborative sorghum research, new innovations including the recently completed sequence of the sorghum genome, fine mapping of loci associated with Striga resistance, discovery of biochemical compounds associated with processing and utilization of sorghum grains, and the development of herbicide-resistant sorghum can be utilized and explored.

Multidisciplinary teams of scientists from a variety sorghum research institutions in Ethiopia, the USDA-ARS and U.S. land grant universities will work together to exploit the wide genetic resources for high yield potential, environmental stress tolerance and improved nutritional quality available among Ethiopian sorghum germplasm. The team also plans to optimize food processing methods in order to maximize availability of nutrients in sorghum-based local diets. A series of interrelated activities will be implemented both in the laboratory and at selected field locations in major sorghum producing regions of the country to discover unique phenotypes related to improved productivity, protein and micronutrient nutrition and develop and select the best variety or hybrid carrying these traits.

The team also plans to utilize genomic tools to locate genes associated with enhanced nutritional value and reduced anti-nutritional factors, such as low protease inhibitor and phytic acid, and enhance breeding efforts for the improvements of many of these traits. Additionally, the team will contribute to building the capacity of human resources and the institutional infrastructure of collaborating national organizations through training and mentoring graduate students to help build the critical mass of scientists capable of solving local and national problems.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change. In addition, this project also supports *Objective II: Incubate and nurture a new wave of feed and food products to stimulate demand for sorghum and millet thereby extending economic benefits beyond the farmgate into the broader population.*

Collaborators

U.S. collaborating institution(s):	Purdue University, Kansas State University, USDA-ARS, KSU – Hays Research Station
Intl. collaborating institution(s):	*Ethiopia* - EIAR (Melkassa Research Center, Sirinka Research Center, Pawe Research Center), Tigray Agricultural Research Institute, Haramaya University

Achievements

Six protease inhibitor (PI) genes were identified, their genomic locations determined, and markers developed to amplify them. As initial effort, a set of (57) tannin-free high- and low-digestible sorghums were selected and screened for variation in protease inhibitor genes. Association of these PI SNPs with protein digestibility showed some linkage but not strong enough to pursue a planned screening of germplasm. This is most likely due to other confounding factors that also cause differences in protein digestibility. Thus the activity was slightly modified to see the effects of natural variation in kafirin gene sequences and link this variability to protein digestibility. This effort identified four natural kafirin alleles (all of them alpha kafirins) that are strongly associated with protein digestibility. Three of these kafirin were (SORBI_3005G185600, SORBI_3005G188800, SORBI_3005G189000) were associated with improved protein digestibility and one of them (SORBI_3005G192801) with reduced protein digestibility. Marker tools have developed and these alleles can be tracked in breeding populations. Future efforts in improving nutritional quality should combine information not only from the kafirin genes and protease inhibitors but also from other antinutritional factors and integrate them in a way they can have synergy in enhancing protein nutrition. In particular, down regulation of gamma kafirin should be an important component of future genetic efforts to enhance protein digestibility.

Capacity building

Individuals trained under this project include:

Alemnesh Bekele	Haramaya University	Master's	Plant pathology/breeding
Yemane Belayneh	Kansas State University	Ph.D.	Plant breeding and genetics
Diriba Hika Chere	Kansas State University	Ph.D.	Plant pathology/breeding

Lessons learned

Protein digestibility is a very complex trait. The standard pepsin assay alone may not be enough to understand all of the biological processes associated with breakdown of proteins in the gut. There is opportunity for enhancing protein digestibility by following certain pre-processing steps and treatments to precipitate compounds interfering with protein nutrition. Increased Fe and Zn, in addition to increasing the availability of these minerals in the diet, will help increase the concentration of phytase in the grain that may breakdown phytic acid, one of the pepsin inhibitory compounds.

Presentations and publications

Bean, S. R., Weerasooriya, D., Nugusu, Y., Ioerger, B., & Tesso, T. The effect of genotype and traditional food processing methods on in-vitro protein digestibility (IVPD) and micronutrient profile of sorghum cooked products. PLOS ONE. doi:10.1371/journal.pone.0203005; Date Aug 13 2018.

Bekele, A., Mekbib, F., & Tesso, T. (April 2018). Genetic variability and characters association of Hararghe sorghum [Sorghum bicolor (L.) Moench] genotypes for grain yield, yield components, grain and nutritional quality. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town South Africa.

Belayneh, Y. G., Morris, G. P., Liu, S., Tadesse, T., Seyoum, A.... (April 2018). The dynamics of tannin presence in Ethiopian sorghum landraces follows climatic clues. Sorghum in the 21st century, Cape Town South Africa.

Duressa, D., Bean, S. R., St Amand, P., & Tesso, T. Identification of α-kafirin alleles associated with protein digestibility in grain sorghum [Sorghum bicolor (L.) Moench]. The Plant Genome. Under review.

Duressa, D., Bean, S. R., St Amand, P., & Tesso, T. (April 2018). Association between kafirin allelic variants and sorghum grain protein digestibility. Presentation at Sorghum in the 21st century, Cape Town South Africa.

Duressa, D., Bean, S. R., Tilley, M., & Tesso, T. Genetic basis of protein digestibility in grain sorghum [Sorghum Bicolor (L.) Moench]. Crop Science. Awaiting publication.

Weerasooriya, D., Bean, S. R., & Tesso, T. (April 2018). The impact of genotype, food processing methods and kafirin composition on digestibility of sorghum proteins. Sorghum in the 21st century, Cape Town South Africa.

Genetic improvement of sorghum and millet for resistance to fungal pathogens
(Led by Dr. Tesfaye Mengiste – Purdue University)

Location (zonal level)
Ethiopia – East Shewa, North Wollo, Addis Ababa, Arsi, East Harerge, West Gojam, South Tigray, East Tigray

Description
Sorghum is an important food security crop in Ethiopia, and is grown in diverse agroecologies with varying climatic characteristics. While some of the most favorable conditions for crop growth occur in west Ethiopia, these conditions are also accompanied by a variety of potentially devastating pathogens.

The goal of the project is to enhance sorghum productivity and improve the livelihood of sorghum farmers in western Ethiopia through a collaborative research program focused on developing new, innovative interventions in crop disease resistance. Local varieties grown in the target regions have evolved under severe pathogen pressure and thus possess powerful alleles for a blend of novel resistance genes. Fungal diseases, anthracnose and grain mold are significant risk-causing pathogens in the target region that can result in significant loss of yield, grain quality deterioration, and are obstacles to growing high yielding varieties with shorter growth durations.

By utilizing the unique local gene pool and other sources of germplasm covering the spectrum of natural variation, this project aims to identify disease resistance to combine with other adaptive traits to create high yielding sorghum varieties and hybrids. This will be achieved through innovative phenotyping and resistance breeding, supported by molecular tools for identification and characterization of genes and alleles in key genomic regions underlying a higher level of disease resistance. The germplasm evaluations that make use of the unique environmental conditions of the target region will be strengthened by next generation sequencing and mapping approaches to identify genes underlying quantitative traits such as grain mold. In parallel, to guide the breeding effort and enhance resistance identification schemes, the prevalence and nature of fungal species causing grain mold and strains of anthracnose in the target area will be studied. Further, the project aims to strengthen the capacity of local research institutions by providing graduate education in critical areas that are likely to boost the capability of the next generation of breeders and plant pathologists.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change.

Collaborators

U.S. collaborating institution(s):	Purdue University, Kansas State University
Intl. collaborating institution(s):	*Ethiopia* - EIAR (Asosa Research Center, Pawe Research Center, Bako Research Center), Holleta Biotechnology Center

Achievements
We established the genetic architecture of natural variation in Ethiopian sorghum germplasm transcending a wide-range of environmental and agro-climatic conditions. Our observations contribute to the characterization of genes and alleles controlling agronomic traits in sorghum. Once the candidate loci associated to traits are validated, molecular markers will be developed and used in marker assisted selection for trait improvement. Finally, the availability of sequences for such a large population of Ethiopian germplasm has laid the foundation for future genetic studies in many different traits. Ultimately, the genetic variants and newly defined loci will contribute to a better understanding of the genetic mechanisms underlying these traits and improvement of the crop.

We discovered new disease resistant germplasm that confer resistance to grain mold and anthracnose. For a subset of these materials, the genes and/or genomic regions carrying the resistance genes have been determined. We identified resistance loci designated as ANTHRACNOSE RESISTANCE GENE 2 (ARG2) and ANTHRACNOSE RESISTANCE GENE 3 (ARG3) in two distinct genotypes of sorghum. The two genotypes were identified based on easily distinguishable disease resistance responses during the initial evaluation. Mapping populations were developed by crossing ARG2 and ARG3 to the highly diseases susceptible genotype TAM428. Genetic analyses of the resistance in the F1 and F2 generations suggested that ARG2 is dominant resistance gene whereas the ARG3 is inherited as a recessive trait.

Capacity building

Individuals trained under this project include:

Fuad Abduselam	Haramaya University	Master's	Agronomy
Chemeda Berhanu	Haramaya University	Master's	Plant pathology/breeding
Kebede Dessalgn	Haramaya University	Master's	Plant pathology/breeding
Demeke Bayable	Purdue University	Ph.D.	Plant pathology
Habte Nida	Purdue University	Ph.D.	Plant breeding and pathology

Lessons learned

As we identify new resistant lines from the screening, development of new populations are being made each season. The identification of the anthracnose resistance loci will help design molecular markers to transfer the resistance genes into widely adapted materials which are often deficient in resistance. The QTL-seq analysis was completed for two of the loci based on sequencing reads of deep sequenced resistant and susceptible bulks at F2 generation. One resistance gene was clearly mapped to an arm of chromosome 5 while the second was mapped to Chromosome 8. During the 2017 season new crossing included 14 parents with 2 newly selected disease resistant lines were realized and therefore from this cross 28 new F1 crosses are expected for generation advance in 2018 season.

Presentations and publications

Bayable, D., Adeyanju, A., Nida, H., Tessema, G. G., & Mengiste, T. (April 2018). Identification and characterization of host resistance genes and mechanisms to sorghum anthracnose. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Desalegn, K., Mekbib, F., & Mengiste, T. (April 2018). Evaluation of selected Ethiopian sorghum [Sorghum bicolor (L.)] genotypes for resistance against anthracnose. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapidly Changing World, Cape Town, South Africa.

Fuyou, F., Tessema, G. G., & Mengiste, T. Prediction and expression profiling of mRNA and small RNA in Colletotrichum sublineolum (Anthracnose) resistant and susceptible sorghum genotypes. BMC Genomics. Awaiting publication.

Mengiste, T. (August 2018). Plant disease resistance: Pathology, mechanisms and applications. Symposium on Plant Genome Dynamics, University of Cambridge, United Kingdom, England.

Mengiste, T. (April 2018). Broad spectrum and complete fungal resistance in sorghum conferred by an intracellular immune receptor. Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Mengiste, T. (August 2018). Plant disease resistance and plant biotechnoloy. Presentation at Haramaya University - African Center of Excellence for Climate-Smart Agriculture, Haramaya University.

Nida, H., Tessema, G. G., Ejeta, G., & Mengiste, T. Identification of sorghum grain mold resistance loci through genome wide association mapping. Journal of Cereal Science.

Nida, H., Tessema, G. G., Ejeta, G., & Mengiste, T. (April 2018). Identification of sorghum grain mold resistance loci through GWAS. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa

Tessema, G. G., Nida, H., Tesso, T., Ejeta, G., & Mengiste, T. A large-scale genome wide association analyses of Ethiopian sorghum landrace collection reveal loci associated with important traits. BMC Genomics. Submitted.

Tessema, G. G., Nida, H., Tesso, T., Ejeta, G., & Mengiste, T. (April 2018). Sorghum genetic diversity study and gene mining for important traits. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapidly Changing World, Cape Town, South Africa.

Yirsaw, M. M., Mengiste, T., Ayana, G., & Tadesse, T. (April 2018). Exploiting the untapped genetic variability of Ethiopian sorghum genotypes for resistance breeding for anthracnose (Colletotrichum sublineolum). Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapid Changing World, Cape Town, South Africa.

Xu, X., Mengiste, T., & Ejeta, G. (April 2018). Identification and mapping of anthracnose resistance genes in sorghum [Sorghum bicolor (L.) Moench]. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Genetic enhancement of sorghum to promote commercial seed supply and grain market development in Ethiopia
(Led by Dr. Gebisa Ejeta - Purdue University)

Other area(s) of inquiry
Added-value products and markets

Location (zonal level)
Ethiopia – East Shewa, North Wollo, Addis Ababa, Arsi, East Harerge, West Gojam, South Tigray, East Tigray

Description
Ethiopian sorghum landraces exhibit native genetic variation for drought and Striga resistance which this project aims to exploit in the development of sorghum cultivars with resistance to these important stresses. The project employs biotechnology, breeding and agronomy to unleash the potential of the crop for Ethiopian farmers. The team is developing a core set of sorghum germplasm population to characterize the inherent variability through large-scale, high-throughput genotyping and coupling this practice with phenotyping of valuable traits under target environments. Data is then treated with appropriate bioinformatics and statistical procedures to identify useful allelic variation for drought and Striga resistance. This will be enhanced by the development of local capacity and the restoration of rigor and discipline to the Ethiopian sorghum breeding program to produce superior sorghum on a regular basis. Project researchers will cooperate with agronomists and economists to develop a package of genetic and crop management practices to control stresses and optimize yields.

At the highest level, the project aims to develop a functional sorghum breeding program in Ethiopia focused on the development of adapted, high-yielding sorghum varieties and hybrids for broad societal impact. The use of hybrid cultivars will be promoted to strengthen the seed supply value chain and catalyze the development of a commercial sorghum seed enterprise system in the country. These activities will serve as part of the larger national effort in building local capacity, strengthening the institutions of education, research, extension, and input systems for development, and for advancing science-based development to impart livelihood change for smallholder sorghum farmers of Ethiopia.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change. In addition, this project also supports *Objective II: Incubate and nurture a new wave of feed and food products to stimulate demand for sorghum and millet thereby extending economic benefits beyond the farmgate into the broader population.*

Collaborators

U.S. collaborating institution(s):	Purdue University, Kansas State University
Intl. collaborating institution(s):	*Ethiopia* - Ethiopian Institute of Agricultural Research (EIAR), (Melkassa Research Center, Sirinka Research Center), Holleta Biotechnology Center, Tigray Regional Program, Oromia Regional Program, Haramaya University

Achievements
A white-seeded hybrid sorghum variety was released. A second sorghum hybrid, a white seeded drought tolerant sorghum hybrid, has been proposed for release. The Ethiopian sorghum germplasm release committee has found the hybrid worthy of release with additional strip tests currently underway to determine the superiority of the hybrid based on how it does under large plot on-farm testing at several locations.

We have generated sorghum germplasm with high tolerance to drought through our annual evaluation of materials that we supply to the Ethiopian sorghum improvement program at EIAR. We have also routinely evaluated new experimental

sorghum hybrids synthesized using these sorghum lines selected for their drought tolerance. Several sorghum hybrids derived from these tests are in the pipeline of the EIAR multilocation trial evaluations that are required for release. These include early maturing sorghum hybrids and stay-green hybrids, both with drought tolerance, as well as high yield potential dual-purpose (grain and forage) hybrids, and brown midrib sorghum-Sudan hybrids for forage. There has been great interest generated for the brown mid-rib forage sorghum hybrids.

Capacity building

Individuals trained under this project include:

Patrick Ongom	Purdue University	Ph.D.	Plant genetics
Xiaochen Xu	Purdue University	Ph.D.	Plant breeding and genetics
Adedayo Adeyanju	Purdue University	Post-doctoral	Plant genetics

Lessons learned

There is considerable potential to develop a broad range of sorghum hybrids meeting multiple production objectives, including forage needs, and incorporate Striga resistance into those hybrids.

Presentations and publications

Bayable, D., Adeyanju, A., Fuyou, F., D., Ejeta, G., & Mengiste, T. (April 2018). Broad spectrum and complete fungal resistance in sorghum conferred by an intracellular immune receptor. Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Ejeta, G. (January 2018). Advancing science, technology, and innovation in sorghum, millets, and other traditional crops through transdisciplinary approaches to transform African agriculture. Presentation at Sorghum in the 21st Century, Cape Town, South Africa.

Ejeta, G. (January 2018). Genome wide association analysis for Striga resistance in sorghum MAGIC population. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Ejeta, G. (April 2018). Enhancing resilience in the face of climate change. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a rapidly changing world, Cape Town, South Africa.

Mengiste, T. & Ejeta, G. (April 2018). Identification and mapping of anthracnose resistance genes in sorghum [Sorghum bicolor (L.) Moench]. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Nida, H., Mengiste, T., & Ejeta, G. (April 2018). Identification of sorghum grain mold resistance loci through GWAS. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Ongom, P. & Ejeta, G. Mating design and genetic structure of a multi-parent advanced generation inter-cross (MAGIC) population of sorghum. Genes Genomes and Genetics. Accepted.

Rich, P., Mekbib, F., & Ejeta, G. (January 2018). Evaluation of Ethiopian Sorghum landraces and wild relatives for pre-attachment resistance mechanisms to Striga infestation. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapidly Changing World, Cape Town, South Africa.

Tessema, G. G., Nida, H., Tesso, T., Ejeta, G., & Mengiste, T. (April 2018). Sorghum genetic diversity study and gene mining for important traits. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapidly Changing World, Cape Town, South Africa.

Improving sorghum adaptation in West Africa with genomics-enabled breeding
(Led by Dr. Geoffrey Morris – Kansas State University)

Location (department level)
Niger – Aguie, Bkonni, Kollo, Niamey, Tillaberi, Say
Senegal – Thies, Bambey, Tambacounda

Description
Improving the productivity, resilience and quality of cereal crops is a major leverage point for development in West Africa because of the potential for impacts in regional trade, rural food security, and the health of women and children. As the starting point for a major agriculture value chain, enhanced sorghum varieties with greater yields and improved yield stability can support agricultural and economic development at regional scale.

This project will use new genomic tools to accelerate marker-assisted breeding and expand its impact in West Africa, with six integrated objectives:

1) Genomic characterization of Senegalese and Nigerien landraces and breeding lines to connect West African breeding programs to global sorghum breeding efforts;
2) Development of a simplified genomics toolkit to increase access to marker-assisted breeding tools in West Africa;
3) Development of multi-parent populations for more efficient trait mapping and breeding which combine traits from locally-preferred varieties and elite global lines;
4) Improved genetic mapping of stress resistance/tolerance traits to generate more effective trait-associated markers;
5) Implementation of Marker Assisted Recurrent Selection to develop more resilient locally-preferred varieties;
6) Long-term and short-term training on genomics-enabled breeding for West African crop scientists.

As sorghum is a major component of the diet of many of sub-Saharan Africa's poorest rural people, the acceleration of sorghum breeding will have numerous outcomes that support Feed the Future objectives. In particular, the proposed project will directly address the USAID strategy for climate-smart agriculture in West Africa by accelerating the development of sorghum varieties with increased resilience to abiotic and biotic stressors.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change. In addition this project also supports *Objective II: Incubate and nurture a new wave of feed and food products to stimulate demand for sorghum and millet thereby extending economic benefits beyond the farmgate into the broader population* as well as *Objective III: Create an economically rationalized business and research investment plan to leverage USAID core financing and attract associate awards and broader donor support.*

Collaborators

U.S. collaborating institution(s):	Kansas State University
Intl. collaborating institution(s):	*France* - Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) *Senegal* - Institut Sénégalais de Recherches Agricoles (ISRA), Centre d'Etudes Régional pour l'Amélioration de l'Adaptation à la Sécheresse (CERAAS), Centre National de Recherche Agronomique (CNRA)

Niger - International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Institut National de la Recherche Agronomique du Niger (INRAN), LSDS (farmer organization), HALAL (farmer organization)

Achievements

We have completed genotyping at 400,000 markers for over 2,000 West African sorghum accessions. The data set allowed us to precisely understand the relationships among West African national landrace collection and breeding populations (Maina et al. 2018, Olatoye et al. 2018, Faye et al. in review). The identification of diagnostic markers to recover local genetic backgrounds is ongoing. These genomics resources are now available to the global sorghum improvement community with raw sequencing data deposited to the NCBI Short Read Archive and genotype data available at Dryad Digital Repository.

GBS-to-KASP conversion is underway for ~100 markers. Development of conversion tools themselves are on hold, pending further development of (i) high-throughput genotyping databases (GOBII, GIGWA) that provide easy access to genomic data and (ii) MAS capabilities in breeder-facing decision support software (BMS or equivalent). A total of 97 SNP-KASP markers were developed. These SNP tag genes involved in maintaining grain weight and number under intermittent or terminal water deficit conditions, in stress tolerance indices, in panicle length, in *Striga* resistance, in protein digestibility, and stay-green trait.

Female producers participated in the selection and/or training Tillabery and Maradi in Niger. Three lines from N13-derived lines from ICRISAT-Ethiopia ((AG-8XN13) BC3F5-32, (TXN13) BC3F5-41, and (AG-8XN13) BC3F5-42) were selected by farmers because of their resistance to *Striga*, yield potential, and their adaptation. These varieties will be used to make crosses with the sorghum program best varieties and landraces to develop *Striga* tolerant genotypes. During participatory selection, farmers and seed producers selected lines from the mini-NAM population at the F4 generation.

Capacity building

Individuals trained under this project include:

Sidi Assoumane	ICRISAT	Bachelor's	Ecophysiology
Nadre Gbedié	CERAAS	Master's	Breeding
Eyanawa Akata Atchozou	CERAAS	Ph.D.	Agronomy (Breeding & Genetics)
Cyril Diatta	CERAAS	Ph.D.	Plant breeding and genetics
Jacques Faye	Kansas State University	Ph.D.	Agronomy (Plant Breeding & Genetics)
Fanna Maina	Kansas State University	Ph.D.	Agronomy (Plant Breeding & Genetics)
Marcus Olatoye	Kansas State University	Ph.D.	Plant breeding and genetics

Lessons learned

Phenotyping capacity is still the major limitation for identification of trait-associated markers. For quantitative trait locus mapping of grain mold, visual rating of naturally-occurring grain mold infection in F3/4 generation mini-NAM lines was inconsistent across years/sites and did not lead to highly predictive trait-associated markers. In future work, reduced genetic variability of RILs and improved phenotyping protocols may produce better trait-associated marker.

Presentations and publications

Akata Atchozou, E. (April 2018). Promising new accessions to improve drought adaptation in sorghum in West Africa. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapidly Changing World, Cape Town, South Africa.

Akata Atchozou, E., Diatta, C., Faye, J. M., Diop, A., Maina, F. A.... (January 2017). Combining ability and heterotic pattern in West African sorghum [Sorghum bicolor (L.) Moench] landraces(pp.491 - 508). African Crop Science Journal, 25(4), Kampala, Uganda. doi:10.4314/acsj.v25i4.7.

Faye, J. M. (April 2018). Population structure and selection signatures in the Senegalese sorghum landraces. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapidly Changing World, Cape Town, South Africa.

Faye, J. M., Maina, F. A., Hu, Z., Fonceka, D., Cissé, N., & Morris, G. P. Genomic signatures of adaptation to Sahelian and Soudanian climates in sorghum landraces of Senegal. Molecular Ecology. Under review.

Maina, F. A. (April 2018). Population genomics of sorghum (Sorghum bicolor) across diverse agroclimatic zones of Niger. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapidly Changing World, Cape Town, South Africa.

Maina, F. A., Bouchet, S., Marla, S., Hu, Z., Wang, J.... (February 2018). Population genomics of sorghum (Sorghum bicolor) across diverse agroclimatic zones of Niger (pp.223-232). Genome, 61(4), Ottawa, Canada. doi:10.1139/gen-2017-0131.

Morris, G. P. (April 2018). Improving sorghum adaptation in West Africa with genomics-enabled breeding. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Olatoye, M. O., Hu, Z., Maina, F. A., & Morris, G. P. (September 2018). Genomic signatures of adaptation to a precipitation gradient in Nigerian sorghum (pp.3269-3281). G3: Genes, Genomes, Genetics, 8(10), Bethesda, USA. doi:10.1534/g3.118.200551.

Trait development pipeline for food and feed value in sorghum
(Led by Dr. Mitchell Tuinstra – Purdue University)

Location (department level)
Niger - Aguie, Bkonni, Kollo, Niamey, Tillaberi, Say
Senegal – Thies, Bambey

Description
Some of the most important regional research issues highlighted by scientists in Niger and Senegal as related to sorghum include the need to develop locally-adapted guinea and non-guinea sorghum varieties and hybrids with improved grain quality characteristics. This project leverages new genetic technologies to address these sorghum crop improvement needs through targeted research, short- and long-term training and education, and technology transfer to promote and enhance sorghum production and impact.

The genetic research and technology transfer in this project makes use of the sorghum genome sequence and a proven population of sequence-indexed mutants as tools to identify and characterize allelic variation in genes that influence four specific grain quality traits, which include protein digestibility, reduced phytic acid content to improve iron bioavailability, modified starch composition, and designer starches with altered gelatinization temperatures. Collaborators in West Africa are conducting research to target modification of grain protein digestibility and forage quality. Those alleles that condition improved end-use value will then be incorporated into locally adapted cultivars and hybrids.

The project's training activities will strengthen sorghum breeding programs across the region and contribute to capacity building in host-country programs while germplasm-enhancement activities will result in technology transfer that contributes to the development of sorghum varieties and hybrids with enhanced food- and feed-quality traits. Farmer participation in evaluation and selection of these varieties will promote acceptance and production of new cultivars and the increased production of high-quality grains will stimulate and support development of new markets.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change. In addition this project also supports *Objective II: Incubate and nurture a new wave of feed and food products to stimulate demand for sorghum and millet thereby extending economic benefits beyond the farmgate into the broader population* as well as *Objective III: Create an economically rationalized business and research investment plan to leverage USAID core financing and attract associate awards and broader donor support.*

Collaborators

U.S. collaborating institution(s):	Purdue University
Intl. collaborating institution(s):	*Senegal* - Institut de Technologie Alimentaire (ITA), CERAAS, ISRA, CNRA *Niger* - INRAN

Achievements
Purdue PIs are working with the sorghum breeders at INRAN and CERAAS to develop breeding programs for new sorghum traits including highly digestible protein, modified starch and improved forage quality introgressed into locally adapted guinea and caudatum varieties. In 2016, crosses were made between OPVs from West Africa and mutants with the highly digestible protein, modified starch quality, and improved forage quality. These populations are being advanced in Senegal, Niger, and the U.S. In 2018, a set of 37 highly digestible selections are being advanced to the F4 generation including several with outstanding food-quality attributes. A set of 47 bmr selections in OPVs from West Africa were

advanced to the F3 and F4 generations. More than 200 breeding lines with modified starch attributes were advanced in breeding populations to the F4 generation.

Elisabeth Diatta, a Ph.D. student from Senegal, used a bulked segregant analysis to reveal that the digestibility phenotype in two of the mutants maps were associated to two different loci on chromosome 5. The highly digestible phenotype of SbEMS1613 was found to be linked to a single point missense mutation on the coding sequence of a 26S proteasome subunit. The highly digestible phenotype of SbEMS3324 is controlled by a single point missense mutation on the coding sequence of a α-Kafirin gene copy. These SNPs will enable marker assisted breeding for introgression of the protein digestibility trait into sorghum elite lines. Stefanie Griebel, a Ph.D. student working on the project identified sorghum EMS mutants with strong ASV phenotypes. Whole genome sequencing of these mutants revealed candidate SNPs in genes related to starch biosynthesis. Sorghum stover is among the most important feed for livestock in Niger based on a participatory rural appraisal (PRA) conducted by Ousmane Seyni, a Ph.D. student working on the project. To increase feed availability and quality, two brown-midrib (bmr) genes (bmr6 and bmr12) are being introgressed into well adapted Nigerien cultivars to generate backcross populations.

Capacity building

Individuals trained under this project include:

Aissatou Diao	CERAAS	Bachelor's	Agronomy
Anna Thiam	CERAAS	Bachelor's	Agronomy
Kader Aidara	CERAAS	Master's	Agroforestry ecology and adaptation
El Hadj Malick Kane	CERAAS	Master's	Microbial and vegetal biotechnology
Anta Sy	CERAAS	Master's	Analytical chemistry
Elizabeth Diatta	West African Center for Crop Improvement	Ph.D.	Plant Breeding
Stephanie Griebel	Purdue University	Ph.D.	Agronomy
Ousmane Seyni	West African Center for Crop Improvement	Ph.D.	Plant Breeding

Lessons learned

More than one candidate gene was identified for increased protein digestibility in SbEMS1613. It may be challenging to identify the causal SNP for this phenotype. Quality assessment is now possible at CERRAS as the lab is fully operational.

Presentations and publications

Abdoul, A. K. (2018) Evaluation of photoperiodic insensitive tannin-free white-grained sorghum inbred lines for yield and resistance to grain mold in Senegal.

Diatta, E., Tuinstra, M., Huggis, E., Thompson, A., Cisse, N.... (April 2018). Mapping Natural and Induced Genetic Variation for Protein Digestibility in Sorghum Grain. Presentation at Sorghum 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Griebel, S., Webb, M. M., Campanella, O., Craig, B., Weil, C., & Tuinstra, M. The Alkali Spreading Phenotype in Sorghum bicolor and its Relationship to Starch Gelatinization. Journal of Cereal Chemistry. Submitted.

Griebel, S., Westerman, R., Weil, C., Hamaker, B. R., Martinez, M.... (April 2018). The Alkali Spreading Phenotype in Sorghum; Identification and Characterization of Genes and Alleles, Influences on Starch Gelatinization Temperature and Resistant Starch. Sorghum 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Kane, E. M. (2018) Variability analysis of phenotypic responses and differential gene expression in sorghum EMS mutants under water stress.

Souley, S., Daouda, T., & Mounkaila, S. (April 2018). Development of new cytoplasmic-genetic male sterile line of BMR sorghum. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapidly Changing World, South Africa.

Sy, A. Y. (2018) Determination of the digestibility of sorghum proteins: a biochemical phenotyping tool for selection.

Development of dual-purpose pearl millet varieties for the benefit of farmers and agro-pastoralists in the Sahelian and Sudanian zones of West Africa
(Led by Dr. Ousmane Sy – ISRA)

Location (department level)
Niger - Aguie, Kollo, Boboye,
Senegal – Bambey, Nioro du Rip
Mali – Segou, Koutiala
Burkina Faso – Ouahigouya, Ougadougou

Description
This project aims to tackle the challenges of both human and animal malnutrition by setting the foundation and developing a strategy for farmer-participatory breeding of highly nutritious, dual-purpose pearl millet varieties in the target countries Senegal, Mali, Burkina Faso and Niger. The development and cultivation of dual-purpose pearl millet varieties with enhanced grain nutritional quality and stover digestibility is expected to contribute to better crop-livestock integration and improved incomes and even nutritional security of smallholder farming families, as called for by the Millennium Development Goals (MDGs).

The project will gather and characterize at least 100 accessions of germplasm from the four countries involved and other millet breeding programs to determine the genetic diversity for stover quality and digestibility traits, grain mineral content, grain and stover yield performance. It will assess the relationships between stover nutritional quality and digestibility and agro-morphological traits, as well as grain micronutrient contents, to understand potential trade-offs in selection of nutritious dual-purpose pearl millet cultivars. The project will also validate superior germplasm accessions in a participatory manner with women and men farmers in large-scale on-farm trials in the target regions, and identify farmer-preferred accessions for use in future dual-purpose pearl millet breeding programs.

The genetic material will be multiplied to make seed available for farm level multi-location trials and complementary grain chemical analyses. At least five superior dual-purpose varieties with good yield and good quality for grain and stover/fodder will finally be selected by country and seed multiplication system involving breeder-foundation and certified seed, will be put in place to make seed available to the users (farmers, agro-pastoralists and others). Capacity building will include stakeholders training on quality seed production techniques, identification of diseases, insects, parasitic weeds and other biotic millet production constraints.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change. In addition, this project also supports *Objective II: Incubate and nurture a new wave of feed and food products to stimulate demand for sorghum and millet thereby extending economic benefits beyond the farmgate into the broader population.*

Collaborators

U.S. collaborating institution(s):	Kansas State University
Intl. collaborating institution(s):	*Senegal* – CERAAS/ISRA
	Niger – INRAN, ICRISAT
	Burkina Faso – INERA
	Mali - IER

Achievements
Pearl millet varieties, landraces and accessions were evaluated in two locations in each of the four countries. In Senegal, the results showed that the most high grain yielding variety in Sahelian zone is SL214 (2,768kg/ha). It is followed by

SL442 (2,691kg/ha) and Thialack2 (2,625kg/ha). For stover production, the best variety is SL106 with 6,585kg/ha, followed by SL214 with 6,330kg/ha. For the grain analysis, the richest variety for iron is NK Moro from Niger. There were also SL69, SL56 from Senegal; IBMV 8402 et PE01203xPE05980R3 that showed a high level of iron content. For fodder analyses, we observe that the highest ADF content belongs to SL214 with 50.55. This variety has also a medium NDF level of 74.72 and a good protein content rate 3.48 mg/kg. This variety is followed by PE08030 from Burkina Faso with 50.25 as ADF, 76.10 as NDF and 3.75 mg/kg as protein content. After these two elite varieties, we have Thialack2 with 49.51 as ADF, 73.63 as NDF and 5.86 mg/kg as protein content.

Regarding the specific objective of assessing relationships between stover nutritional quality and digestibility and other agro-morphological traits, the grain quality of the different accessions have been sent to Niger at ICRISAT Sahelian Center for iron and zinc content. The results assisted in the selection of the 15 best entrees for each agroecological zone. Fodder samples were sent to Kansas State University (KSU) as well as the Universite de Thies for analyses of ADF, NDF and protein content. With the help of ICRISAT, Universite of Thies and KSU, this objective has been completed.

The objective of identifying three to five farmer-preferred accessions for future promotion and use in pearl millet dual-purpose variety development has also been successful. At the end of this second year of on-farm trials, 15 entrees were tested and we will be able to select with participatory breeding system, to identify three to five good varieties for certification and cultivation at an on-farm field level in each agro ecological zone. The farmers must have a panel of diversified varieties where the most adapted one according to the agro climatic conditions can be selected. We will dispose of a group of early, medium and long duration varieties and according to the meteorological conditions and choose the most adapted variety to sow. This objective is 75% completed and will be finalized by the end of this 2018 rainy season.

Capacity building

Individuals trained under this project include:

Siby Boubacar	Universite Prive de Segou Agri SUP	Bachelor's	Agronomy
Abdou Illiassou	Universite Dan Dicko Dankoulodo	Master's	Agronomy
Benoit Ouedraogo	University of Ouagadougou	Master's	Breeding and conservation of seed
Zongo Rachelle Yvonne	INERA	Master's	Seed selection and conservation (SELCOSE)

Lessons learned

Considerable variation in quantitative and qualitative traits provides a new resource for pearl millet improvement in West Africa.

Presentations and publications

None reported during this period.

Assessment of pearl millet production problems in West Africa and molecular diversity analysis of pearl millet parental lines

(Led by Dr. Desalegn Serba – Kansas State University)

Location (department level)

Niger - Aguie, Boboye
Senegal – Bambey

Description

Pearl millet is an important staple food and fodder crop in West Africa especially in Mali, Senegal, Niger, and Burkina Faso. However, the productivity is still low as compared to the genetic potential of the crop. Different biotic and abiotic constraints are expected to contribute to the low productivity. To identify a priority area for future research a professional assessment will be conducted through informal survey and preliminary evaluation nursery of germplasm. A total of 100 entries comprising of inbred lines, experimental hybrids, and open pollinated germplasm were assembled and being evaluated in Niger and Senegal. Informal survey of the production problems will be conducted in all four countries to identify a boarder-cutting production problem that need a collaborative research intervention.

Pearl millet breeding research at the Agricultural Research Center-Hays developed several parental lines in the 1980s and 1990s using mainly phenotypic evaluation. The newly initiated breeding program also assembled germplasm from various sources. The level of diversity of these materials has not been documented well. Molecular diversity analysis of these materials will aid to identify novel alleles for different important traits. Therefore, a next-generation sequencing technology called genotyping-by-sequencing will be used to genotype the materials and diversity analysis will be conducted using high throughput SNP markers. The outcome of this diversity analysis will apparently help in founding preliminary heterotic groups and conduct efficient hybrid breeding program.

Theory of change and impact pathways

All research projects contribute towards *Objective I* of our theory of change.

Collaborators

U.S. collaborating institution(s):	Kansas State University
Intl. collaborating institution(s):	*Senegal* - ISRA
	Niger – INRAN
	Burkina Faso – INERA
	Mali - IER

Achievements

The accessions, hybrids, and inbred lines evaluated at two representative locations in the Sahelian zone several high yielding hybrids, accessions with good level of downy mildew resistance were identified.

A total of 400 samples were sequenced three times on Ion Proton. More than 540 million unique reads were obtained. A total of 103,186,800 markers were identified using the TASSEL5-reference pipeline against the new pearl millet reference genome. After filtering the SNPs for 20% missing, 1% MAF, and InDels 82, a total of 112 genome-wide SNPs markers were discovered. An approximate average marker density of 48.3 per Mb of the genome was calculated. The population structure analysis identified six sub-populations that mostly overlap with the genetic origin of the germplasm accessions/source of inbred lines. The principal component analysis showed the population structure and within subpopulation diversity as PCA1 and PCA2 explained less than 10% of the genetic diversity of the population (Figure 1). A neighbor-joining phylogeny analysis grouped the materials into 12 sub-clusters with West Africa as a base. Most clusters were formed among the inbred lines developed in the U.S. Genome-wide linkage disequilibrium analysis and

findings show the faster LD decay in West African sub-population than the rest of the sub-populations. Assessment of genome-wide patterns of nucleotide variation within each sub-population revealed that average genome-wide FST is higher in the Middle East followed by East Africa. The differentiation within Indian sub-population was low.

Capacity building

No students at this time.

Lessons learned

Top cross hybrids are the way to go for the region as it maintains variability in the cultivar for any stresses.

Presentations and publications

Serba, D. D. (August 2017). Status of Global Pearl Millet Breeding Programs and the Way Forward (pp.2891-2905). Crop Science, 57(6), USA. doi:doi:10.2135/cropsci2016.11.0936.

Serba, D. D. Pearl millet: A resilient crop for arid and semi-arid environments, Genomic Designing of Climate-Smart Cereal Crops. Springer Nature. Submitted.

AREA OF INQUIRY: Productions systems management

Development of biotic stress-resistant sorghum cultivars for Niger and Senegal

(Led by Dr. Bonnie Pendleton – West Texas A&M University)

Other area(s) of inquiry

Genetic enhancement
Added-value products and markets

Location (department level)

Niger - Aguie, Bkonni, Kollo, Tillaberi
Senegal – Thies, Bambey

Description

This multi-disciplinary research project includes entomology, breeding, and agricultural economics to develop, evaluate, and deploy sorghum genotypes resistant to abiotic and biotic stresses and adapted to indigenous production and storage systems in West Africa. An integrated approach will increase agricultural productivity and economic growth, with attention to human nutrition, environmental conservation, development of host-country capacity, and gender equity.

In this project, sorghum genotypes with resistance to important stressors in West Africa and the U.S will be selected for managing abiotic and biotic constraints. Sorghums that flower when sorghum midges are present in the field will be evaluated to develop resistance to sorghum midge. Research on sorghum time of flowering in relation to environmental factors will be used to verify the genetic basis of resistance.

Additionally, germplasm resistant to grain mold and weathering in a range of environments will be introgressed into sorghums adapted to Niger and Senegal. To protect stored grain, environmentally friendly methods including hermetic storage and plants with natural insecticidal properties will be evaluated. Scanning electron microscopy of the structure of sorghum kernels resistant to storage insects will be used to increase efficiency for evaluating sorghum genotypes for resistance.

Extension will assist in teaching farmers to identify and manage biotic constraints in the field and storage. Human capacity will be improved by educating scientists in conventional and molecular research methodology and in graduate degree programs. Production profitability and marketing opportunities for sorghum cultivars with increased resistance to abiotic and biotic stresses will be assessed to ensure farmer adoption in West Africa. In all, this project is improving human nutrition, human capacity, and environmental conservation while increasing productivity and economic growth for sorghum.

Theory of change and impact pathways

All research projects contribute towards *Objective I* of our theory of change. In addition, this project also supports *Objective III: Create an economically rationalized business and research investment plan to leverage USAID core financing and attract associate awards and broader donor support.*

Collaborators

U.S. collaborating institution(s): West Texas A&M University, Texas A&M AgriLife Research
Intl. collaborating institution(s): *Senegal* - ISRA, CNRA, CERAAS
Niger - INRAN

Achievements

Sorghum seeds from Texas A&M AgriLife Research at Lubbock were packaged and sent to Niger and Senegal for evaluating for resistance to stresses. Nurseries were planted at three locations in Niger in summer 2018: International Disease and Insect Nursery (IDIN) at Bengou, Midge Line Test (MLT) at Konni, and International Drought Line Test (IDLT) at Lossa. The IDIN and IDLT are provided to collaborators so each can select germplasm that may be useful as a parent in a breeding and selection program. While on a field trip to the research station, the technician viewed and recorded preliminary data on plant growth and evaluated resistance against biotic and abiotic stresses in Niger. A second visit has been planned for this fall 2018 for the technician to return and record data on booting and flowering sorghum, as well as monitoring resistance to biotic and abiotic stresses. Additional field trips will be planned to record data through harvest.

Natural insecticides from four botanicals were evaluated for control of maize weevil, *Sitophilus zeamais*, in Texas. Deterrence tests were done to evaluate the feeding behavior of maize weevils on sorghum treated with botanicals as compared to non-treated sorghum. In 2018, additional chemical analyses including HPLC and NMR were used to assess the chemical composition of the botanicals. Results are being analyzed and will be reported in the dissertation of the Niger Ph.D. student at West Texas A&M University. A Ph.D. student in Senegal found that after three months in storage, more adult *Tribolium* emerged from three varieties, with most (76 adults) emerging from CE-180-33 sorghum. Fewest storage insects (0 to 5) emerged from kernels of Sureno and Macia. *Ephestia kuehniella* caused most damage to all sorghum genotypes except Sureno and Macia that were only 2.4 and 6.9% damaged, respectively. At a one-day scientific conference on 30 May 2018, 54 stake-holders were told our research results and informed how to manage insect pests of stored sorghum grain in West Africa.

Capacity building

Individuals trained under this project include:

Mame More Kasse	ISFAR/University of Thies	Engineer	Agricultural Engineering
Adama Sarr	ISFAR/University of Thies	Engineer	Agricultural Engineering
Omar Kendji	University Cheikh Anta Diop	Master's	Pest Management
Marietou Ly	ENSA/University of Thies	Master's	Sustainable development and society/agriculture
Gnilane Sene	University Cheikh Anta Diop	Master's	Pest management
Hame Abdou Kadi Kadi	West Texas A&M University	Ph.D.	Plant, Soil and Environmental Science - Insect Pest Management
Adja Thiam	University of Thies	Ph.D.	Pest management
Fatou Welle	University Cheikh Anta Diop	Ph.D.	Pest management

Lessons learned

The focus of research on sorghum resistance to sorghum midge by determining the daily time when sorghum midges are present in sorghum fields cross-referenced against the flowering time of spikelets of sorghum was diverted to recording data on resistance to sorghum midge, diseases, and other factors in Senegal because of difficulties in measuring midge presence and flowering time.

Presentations and publications

Abdou Kadi Kadi, H. & Pendleton, B. B. (November 2017). Alternative control strategies to reduce damages by storage insect pests of sorghum grain in Niger (West Africa). Annual Meeting of the Entomological Society of America, Denver, Colorado.

Abdou Kadi Kadi, H. & Pendleton, B. B. (January 2018). Assessing diversity of and alternative management strategies for insect pests of stored sorghum. Presentation at Sorghum Improvement Conference of North America (SICNA 2018), St. Louis, Missouri.

Abdou Kadi Kadi, H. & Pendleton, B. B. (March 2018). Assessing diversity of and alternative management strategies for insect pests of stored sorghum. 3th Annual Faculty Research Poster Session, Canyon, Texas.

Abdou Kadi Kadi, H. & Pendleton, B. B. (March 2018). Evaluating botanicals to control maize weevil (Coleoptera: Curculionidae) in stored sorghum grain. 2018 Meeting of the Southwestern Branch of Entomological Society of America, Albuquerque, New Mexico.

Abdou Kadi Kadi, H. & Pendleton, B. B. (April 2018). Evaluating local botanicals for control of red flour beetle, Tribolium castaneum Herbst (Coleoptera: Tenebrionidae) in sorghum grain. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Abdou Kadi Kadi, H. & B.Pendleton, B. (May 2018). Developpement des variétés de sorgho résistantes aux contraintes biotiques au Niger. Conference des Mercredis, 30 May 2018, Niamey, Niger, Niamey, Niger.

Almas, L., Pendleton, B. B., & Guerrero, B. (April 2018). Climate variability and risk analysis of grain sorghum production in the Texas panhandle. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Chisi, M. & Peterson, G.. Breeding and Agronomy. Chapter 2, Sorghum and Millets. AACC. Awaiting publication.

Kandji, O. (2018) Dynamique des populations de la cecidomyie du sorgho Stenodiplosis sorghicola (Diptera: Cecidomyiidae) et cycle de developpement des lignees de sorgho (Sorghum bicolor (L.) Moench) dans la zone de Roff (Mbour).

Marietou, L. (2018) Evaluation de la resistance aux maladies et insectes ravageurs de lignees de sorgho texanes (Sorghum bicolor (L.) Moench) en rapport avec leurs cycles de developpement dans la zone de Nioro du RIP.

Peterson, G. C., Armstrong, J., B.Pendleton, B., & Stelter, M. (June 2018). Registration of Tx3410 through Tx3428 sorghum germplasm resistant to sugarcane aphid [Melanaphis sacchari (Zehntner)]. Journal of Plant Registrations.

Peterson, G. C., Stelter, M., Armstrong, S., & Pendleton, B. B. (April 2018). Developing sugarcane aphid resistant germplasm in the United States. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Pendleton, B. B. (2018). Sorghum breeding for biotic stress tolerance, Achieving sustainable cultivation of sorghum (pp.345-375). Burleigh Dodds Science Publishing, 1, Cambridge, UK.

Pendleton, B. B. & Hamé, A. (March 2018). Assessing diversity of and alternative management strategies for insect pests of stored sorghum. Presentation at 13th Faculty Research Poster Session and Research Fair, Canyon, TX.

Pendleton, B. B., Peterson, G., Abdou Kadi Kadi, H., Sarr, I., Souley, S., & Mamadou, A. (April 2018). Development of biotic stress-resistant sorghum cultivars for Niger and Senegal. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Perumal, R., Magill, C., Peterson, G., Prom, L., Tesso, T.... (2018). Sorghum breeding for biotic stress tolerance, Achieving sustainable cultivation of sorghum (pp.189-226). Burleigh Dodds Science Publishing, 1, Cambridge, UK.

Sarr, I., Sene, G., Sarr, A., Ly, M., Pendleton, B. B.... (April 2018). Evaluation of sorghum lines for resistance to diseases and insect pests in Senegal. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapid Changing World, Cape Town, South Africa.

Thiam, A. N. (2018) Evaluation de la resistance a la cecidomyie de divers genotypes ou varietes de sorgho et effect de la periode de floraison sur leur tolerance au Senegal.

Thiam, A. N., Sarr, I., Kandji, O., Cissé, N., Pendleton, B. B., Peterson, G. C., & NDiaye, S. (June 2018). Occurrence of the midge (Stenodiplosis sorghicola, Diptera: Cecidomiyidae), development cycle and resistance of different sorghum lines in Senegal. Presentation at Doctoriales (2eme Edition) 2018, University of Thies auditorium (Thies, Senegal).

Thiam, A. N., Sarr, I., Kandji, O., Cissé, N., Pendleton, B. B., Peterson, G. C., & NDiaye, S. (April 2018). Occurrence of the midge (Stenodiplosis sorghicola, Diptera: Cecidomyiidae), development cycle and resistance of different sorghum lines in Senegal. Presentation at Sorghum 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Triplett, E. L. & Pendleton, B. B. (October 2017). Effect of photoperiod on sugarcane aphid, Melanaphis sacchari, on sorghum. Presentation at Annual Meeting of the Entomological Society of America, Denver, Colorado.

Triplett, E. L. & Pendleton, B. B. (March 2018). Evaluating the effect of photoperiod on fitness of sugarcane aphid, Melanaphis sacchari, on sorghum. Presentation at 66th Annual Meeting of the Southwestern Branch of the Entomological Society of America, Albuquerque, New Mexico.

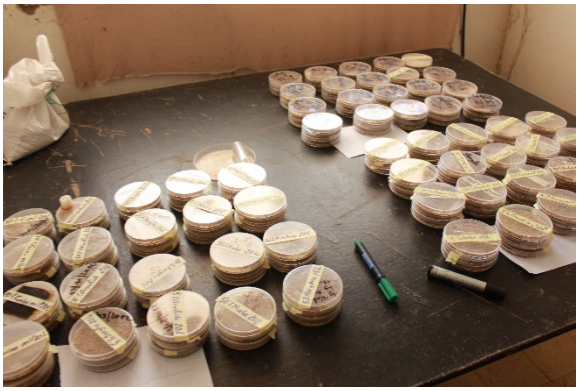
Triplett, E. L. & Pendleton, B. B. (January 2018). Effect of photoperiod on sugarcane aphid, Melanaphis sacchari, on sorghum. Presentation at Sorghum Improvement Conference of North America, St. Louis, Missouri.

Triplett, E. L. & Pendleton, B. B. (March 2018). Evaluating the effect of photoperiod on fitness of sugarcane aphid, Melanaphis sacchari, on sorghum. 66th Annual Meeting of the Southwestern Branch of the Entomological Society of America, Albuquerque, New Mexico.

Welle, F. (2018) Evaluation de la resistance varietale et de methodes alternatives pour la gestion des principaux insectes des stocks du mil/sorgho au Senegal.

Welle, F., Sarr, I., Gueye, M. T., Diarra, K., Pendleton, B. B., & Peterson, G. C. (April 2018). Resistance of sorghum lines to storage insects in Senegal. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapidly Changing World, Cape Town, South Africa.

Biological control of the millet head miner in Niger and Senegal
(Led by Dr. Malick Ba – ICRISAT, Niger)



Location (department level)
Niger - Aguie, Say, Tahou, Dosso, Magaria, Tera
Senegal – Thies, Bambey
Burkina Faso - Ouahigouya

Description
The Millet Head Miner (MHM) is a major chronic insect pest of millet in the Sahel. This project will serve to develop technologies for controlling the MHM, with intentions to significantly decrease the devastating losses that it can inflict (often ranging from 40-85%) on millet yields. Improved management of this key pest will result in increased pearl millet productivity and greater income and food security among millet farmers.

The proposed project includes three primary components:

1) Biological control of the MHM with releases of larval parasitoids to significantly increase on-going mass rearing of the larval parasitoid *Habrabracon hebetor* Say (Hymenoptera: Braconidae) and fine-tune release techniques for improved control of the MHM.
2) Test the *Trichogrammatoidae* egg parasitoid as bio control agents of the MHM.
3) Establishing parasitoid cottage industry for rearing and commercialization of parasitoids in the Sahel with particular attention to having those businesses owned and operated by individuals or groups of women.

The project will train one M.S. and two Ph.D. students at Virginia Tech as well as the University Cheikh Anta Diop in Senegal. Farmers will be trained on biological control of the millet head miner and links will be made with a McKnight-funded project in Burkina Faso, Mali and Niger, a West-Africa Agricultural Productivity Program-funded project in Senegal and the CGIAR research program on Dryland Cereals to scale up the technologies in all Sahelian countries. Outcomes of this project will include a reduction in pearl millet grain losses, an increase in food production and security among Nigerien and Senegalese millet farmers, as well as the establishment of a cottage industry to rear and sell natural enemies, which will provide revenue to farmers and women's cooperatives.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change. In addition this project also supports *Objective III: Create an economically rationalized business and research investment plan to leverage USAID core financing and attract associate awards and broader donor support.*

Collaborators

U.S. collaborating institution(s):	Virginia Tech University, IPM Innovation Lab
Intl. collaborating institution(s):	*Senegal* - ISRA, CERAAS, University Cheikh Anta Diop de Dakar *Niger* - University of Maradi, INRAN

Achievements
We conducted laboratory trials evaluating pearl millet, sorghum, peanut and cowpea as diet sources because these are locally grown and commonly available in Niger. Pearl millet was tested individually as well as mixed with sorghum, cowpea and peanut in the first experiment and with different portions of cowpea in the second experiment. There was no significant difference among treatments in larval duration of post embryonic development. A high number of eggs per female moth was recorded from females fed on cereals combined with legumes. Also, a high number of 4.9 *H.*

*hebetor*larvae/*C. cephalonica*larva, were produced on larvae fed on a diet of 75% pearl millet + 25% cowpea. However, more *C. cephalonica*larvae were produced in the 50% pearl millet +50% cowpea diet and as a result, this diet produced more parasitoids. Twenty-five *C.cephalonica* larvae kept for a three-month rearing period will produce 2,680,257 larvae and 10,077,766 *H. hebetor* adults parasitoids. Mr. Laouali Amadou, who conducted research under the project, was awarded the BIFAD Award of Excellence for Graduate Student Research.

We have started the commercialization of the parasitoids in Niger with six private units which commercialized about 6,000 parasitoid bags. We have provided some backstopping to the private unit and supply them with the insects needed to start the business. We have managed to include the pearl millet IPM in the technologies to be disseminated under the African development Bank funded project "Technologies for African Agriculture Transformation (TAAT)."

Capacity building

Individuals trained under this project include:

Michael Guerci	Virginia Tech	Master's	Agricultural Economics
Hamidou Idrissa	Université Abdou Moumouni de Niamey	Master's	Entomology
Said Laminou	Université Abdou Moumouni de Niamey	Master's	Entomology
Oumou Moumouni	Abdou Moumouni University of Niamey with Short Training at Virginia Tech	Master's	Agricultural Economics
Baye Thiam	University of Thies	Master's	Agricultural engineering
Laouali Amadou	University of Maradi	Ph.D.	Entomology
Mame Fatoumata Goudiaby	University Cheikh Anta Diop	Ph.D.	Entomology
Laouali Karimoune	ICRISAT – Niger	Ph.D.	Entomology

Lessons learned

We are yet to identify a suitable host for a second MHM egg parasitoid (Telenomus spp) to enable carrying out studies on interspecific competition.

Presentations and publications

Ba, M., Karimoune, L., Baoua, I., & Rangaswamy, M. (November 2017). Prospect for use of the egg parasitoid, Trichogrammatoidae armigera N. (Hymenoptera: Trichogrammatidae) against key pearl millet insect in the Sahel. Entomological Society of America 65th Annual Meeting, Denver, Colorado, USA.

Goudiaby, M. F. (2018) Techniques d'elevage et de lacher des parasitoides Bracon hebetor: Formation des produteurs dans le Bassin arachidier.

Goudiaby, M., Sarr, I., Ba, M. N., Sembene, M., & Rangaswamy, M. (September 2018). Efficacy of augmentative release of the parasitoid wasp Bracon hebetor against the pearl millet headminer. Presentation at First International Conference on Biological Control: Approaches and Applications, India, Bengaluru.

Guerci, M., Norton, G., & Ba, M. (2018) Economic feasibility of an augmentative biological control industry in Niger. Crop Protection.

Guerci, M. J., Norton, G. W., Ba, M. N., Baoua, I., Alwang, J.... (August 2018). Economic feasibility of an augmentative biological control industry in Niger(pp.34-40). Crop Protection, 110, Elsevier Ltd. doi:10.1016/j.cropro.2018.03.014.

Karimoune, L., Ba, M. N., Ibrahim, B., & Rangaswamy, M. (August 2018). The parasitoid Trichogrammatoidea armigera Nagaraja (Hymenoptera: Trichogrammatidae) is a potential candidate for biological control of the millet head miner Heliocheilus albipunctella (de Joannis) (Lepidoptera: Noctuidae) in the Sahel (pp.9-16). Biological Control, 127, Elsevier Ltd. doi:10.1016/j.biocontrol.2018.08.003.

Laouali, A., Ba, M. N., Baoua, I., & Rangaswamy, M. Timing of releases of the parasitoid Habrobracon hebetor Say (Hymenoptera: Braconidae) and numbers needed in augmentative biological control against the millet head miner Heliocheilus albipunctella (de Joannis) (Lepidoptera: Noctuidae). Biocontrol. Submitted.

Laouali, A., Baoua, I., Ba, M. N., & Rangaswamy, M. Development of an optimum diet for mass rearing of the rice meal moth Corcyra cephalonica Stainton (Lepidoptera: Pyralidae) and production of the parasitoid Habrobracon hebetor Say (Hymenoptera: Braconidae) for the control of pearl millet head miner. Journal of Insect science. Submitted.

Optimization of the seed ball technology for pearl millet, and agronomic and socio-economic evaluation in the context of smallholder farmers in Senegal and Niger
(Led by Dr. Ludger Herrmann - University of Hohenheim)

Location (department level)
Niger - Aguie
Senegal – Bambey

Description
Pearl millet farmers in Senegal and Niger face many challenges related to crop production, one of which is seeding survival. Technologies that enhance seedling survival in the Sahel present the potential of an important contribution to reduce overall cropping risks in the region, thereby enhancing pearl millet productivity and yield stability.

This project pursues the seed ball technology as a valid option to reduce cropping risks and improve farmers' yields - particularly for female farmers - by using low-cost resources that are readily available. The seed ball technology represents a special form of seed pelleting with natural loam and additives including wood ash from cooking places and chemical fertilizers in micro-dosages, to enhance early plant establishment and plant development. In a highly interdisciplinary and participatory approach the team's research activities will:

1) Further optimize the seed ball technology for pearl millet;
2) Validate the seed ball technology under Sahelian field conditions and determine the agronomic and socio-economic benefits for farmers; and
3) Strengthen local capacity for seed ball research and application in Senegal and Niger.

These objectives are being achieved by including smallholder farmers, farmer organizations, local and international research institutions and multimedia in a continued process of seed ball development, refinement, validation and adaptation to local conditions. At least four local Master's students will be trained and results will be communicated widely. The overarching project objective will be achieved when Sahelian subsistence farmers are able to create seed balls independently and can benefit from a reduced likelihood of cropping failures, improved early plant establishment and grain yield formation.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change. In addition, this project also supports *Objective III: Create an economically rationalized business and research investment plan to leverage USAID core financing and attract associate awards and broader donor support.*

Collaborators
Intl. collaborating institution(s): *Senegal* - ISRA, FAPAL (farmer organization)
Niger - INRAN, Fuma Gaskiya (farmer organization)

Achievements
Additional field testing of pearl millet seedballs was conducted with nearly 2000 farmers in several villages of Niger. Dry and wet sowing were further tested in the farmer environment. In fact, farmers adapt to the annual weather conditions. If the rainy season comes late, dry sowing is practiced. If the rainy season starts normal, farmers opt for wet sowing. The agronomic performance of the seedball technology was shown under numerous circumstances (gender, soil type, sowing conditions, additional management measures). Participatory on-farm trials have reached a large farmer community (>2000) and, in particular, women (80%). Average yield gain independent of gender or soil type is about 30% panicle yield. No economic evaluation is available at this date, but if we assume 40 hours workload for seedball production for 1ha (i.e. 10,000 seedballs) and a daily fare of 2500 FCFA per worker, production costs are about 12500

FCFA. Local materials (mainly sand) are at nearly no cost. Given 200 FCFA per kg grain the simplified economic breakeven is at about 65 kg grain yield increase. Two scientific publications have been released in 2018 on pre-requisites and functioning of the seedball technology. A third one on technology development has been submitted and is under review.

The poster on seedball production was prepared in Haoussa. A video on seedball production was produced at the local level by the farmer organization Fuma Gaskiya. Another farmer organization MORIBEN from western Niger sent delegates from Tera and Falwel to visit Fuma Gaskiya and learn about new technologies, including seedballs. Fuma Gaskiya and INRAN jointly managed this event in September 2018.

Building upon research and testing of the pearl millet seedball, the concept was tested for sorghum. The diameter needs to be a bit greater than with pearl millet, since seed size is greater. As with pearl millet, neither wood ash nor NPK used in the amount tested for pearl millet hampered germination. An open question is, whether content of either wood ash or NPK could be further increased.

Capacity building

Individuals trained under this project include:

Iro Ousseini	INRAN	Bachelor's	Agronomy
Daouda Abassa	INRAN	Master's	Socio-economy
Cheikh Dieng	ENSA Thies	Master's	Production Végétales
Mouhamadou Diome	ENSA Thies	Master's	Socio-economy
Lena Geiger	INRAN	Master's	Agronomy/soil science
Mahamadou Maazou	University of Tahoua	Master's	Socio-economy
Charles Nwankwo	University of Hohenheim	Ph.D.	Agriculture

Lessons learned

Large on-farm trials present the opportunity to identify benefits under uncontrolled situations but it is not easy to implement clear counterfactuals to determine the benefit.

Presentations and publications

Nwankwo, C. I. & Herrmann, L. (April 2018). Viability of the Seedball Technology to Improve Pearl Millet Seedlings Establishment Under Sahelian Conditions - A Review of Pre-Requisites and Environmental Conditions (pp.261-268). International Journal of Agriculture Innovations and Research, 6(5), India. 2319-1473.

Nwankwo, C. I., Herrmann, L., & Neumann, G. (September 2017). Seedball technology improves pearl millet yield in the Sahelian production systems. Tropentag 2017, Bonn, Germany. http://www.tropentag.de/2017/abstracts/links/Nwankwo_mhllpShQ.php.

Nwankwo, C. I., Neumann, G., & Herrmann, L. (September 2017). Seedball induced changes of root growth and physico-chemical properties in the rhizosphere of pearl millet seedlings. Tropentag 2017, Bonn, Germany. http://www.tropentag.de/2017/abstracts/links/Nwankwo_N4hSao9q.php.

Nwankwo, C. I., Neumann, G., & Herrmann, L. (August 2018). Seedball-induced changes of root growth and physico-chemical properties - a case study with pearl millet (pp.768-776). Journal of Plant Nutrition and Soil Science, 181(5), Weinheim, Germany. doi:10.1002/jpln.201800059.

AREA OF INQUIRY: Added-value products and markets

Developing superior functionality in sorghum for food applications to promote sorghum value chain in Ethiopia

(Led by Dr. Joseph Awika – Texas A&M University)

Location (department level)

Ethiopia - Sidama

Description

Two major bottlenecks on sorghum utilization for food in Ethiopia's growing urban markets are its inadequate functionality as a food ingredient and inferior protein nutritional quality (low lysine and poor digestibility). To combat these characteristics, Texas A&M University has developed a set of sorghum parental lines and hybrids that combine waxy and heterowaxy traits (WX/HX) with the high lysine, high protein digestibility (HPD) trait into high performing hybrids and inbred cultivars. The WX/HX-HPD sorghums have desirable end-use characteristics, including more efficient fermentation for ethanol, better protein quality co-product (high lysine) for feed and other uses, and better functionality in batters and dough systems. In this project, Dr. Awika and his research team will test the hypothesis that the improved WX/HX-HPD sorghums will demonstrate significantly better functionality as a food ingredient in dough and batter systems, producing superior quality grain-based products, and that products made with WX/HX-HPD sorghums will demonstrate superior protein nutritional quality for infants and young children from poor households.

The three research objectives for this project include:

1) Establish the effect of combining waxy-heterowaxy (WX/HX) with HPD sorghum traits on dough and batter rheology, food processing, and quality profile of selected traditional and commercial grain-based food products popular in Ethiopia;
2) Establish the suitability of the WX/HX-HPD sorghum hybrids for malting and commercial brewing; and
3) Evaluate the performance and adaptation of the WX/HX-HPD sorghum hybrids in Ethiopia.

Addressing these objectives will lead to development of superior quality sorghum-based food products that will open new markets and enhance the value-chain of sorghum, benefit small-scale sorghum producers and small- and medium-scale food enterprises (SMEs), and limit the effects of poor nutrition in children.

Theory of change and impact pathways

All research projects contribute towards *Objective I* of our theory of change. In addition, this project also supports *Objective II: Incubate and nurture a new wave of feed and food products to stimulate demand for sorghum and millet thereby extending economic benefits beyond the farmgate into the broader population.*

Collaborators

U.S. collaborating institution(s):	Texas A&M University
Intl. collaborating institution(s):	*Ethiopia* - Hawassa University
	South Africa - University of Pretoria

Achievements

For this year we used controlled laboratory conditions to determine the effect of the HD/WX traits on performance of sorghum as a partial substitute for wheat in various model baked products. This is essential to establish the specific

mechanisms by which the HD protein body interacts with starch to impact food quality. The findings will allow us to develop/recommend the appropriate processing technologies to optimize the functional benefits of the new sorghums.

- *Batter-based product, pancake:* compared to normal sorghum, the HD trait produced significantly higher batter viscosity and produced pancakes that were softer, higher in moisture and had overall better textural attributes at 50% and 100% sorghum replacement. The WX trait further enhanced the performance of the HD sorghum in the pancakes by increasing batter viscosity more than 2X, whereas this effect was not seen in normal (LD) sorghum. The data generally agrees with previous year's findings with injera, where the HD trait significantly improved sensory quality of injera.

- *Dough based product, bread;* Both sour dough and yeast fermented doughs were tested. This work is on-going but preliminary data indicate that the yeast fermented doughs produced softer products with higher loaf volume, which is expected. The HD sorghum substitution at both 10 and 20% produced breads that were more cohesive, but had a slightly lower volume and firmer texture than the normal sorghum. This suggests that the HD proteins interact with starch in a way that significantly impacts viscosity during baking and subsequent product expansion. This was clearly evident in the fact that the combined HD/WX trait significantly increased cohesiveness and firmness of the bread, whereas the combining LD/WX trait had no effect. The finding is interesting and suggests the HD trait may enhance performance of sorghum in gluten free and weak gluten products (like cakes) where viscosity development during baking is critical.

- *Semi-batter-based product, cookies;* work in progress.

Based on the good adaptability of the IHD lines in Ethiopia, developing a hybrid seed production system locally would be the most logical next step. Due to the long-term nature of such undertaking, a second phase would be the ideal stage to initiate it. We are currently working with EIAR to identify the logistics necessary to establish regional seed production and demonstration fields in Ethiopia.

Capacity building

Individuals trained under this project include:

Getahun Adane	Hawassa University	Master's	Food science and postharvest technology
Loza Mengistu	Hawassa University	Master's	Food Processing and Preservation
Abadi Mezgebe	University of Pretoria	Ph.D.	Food Science
Tadesse Teferra	Texas A&M	Ph.D.	Food Science

Lessons learned

Achieving equitable enrollment of females in the different training activities remains an on-going challenge.

Presentations and publications

Elhassan, M., Oguntoyinbo, S., Taylor, J., & Taylor, J. (September 2017). Formation and properties of viscoelastic masses made from kafirin by a process of simple coacervation from solution in glacial acetic acid using water (pp.333-342). Food Chemistry, 239, Oxford, United Kingdom. 0308-8146.

Mezgebe, A. G., Taylor, J. R., & Abegaz, K. (January 2018). Relationship between waxy (high amylopectin) and high protein digestibility traits in sorghum and malting quality (pp.319-327). Journal of Cereal Science, Volume 79, New York. doi:https://doi.org/10.1016/j.jcs.2017.11.015.

Teferra, T., Amoako, D., Rooney, W. L., & Awika, J. M. (September 2018). Qualitative assessment of 'highly digestible' protein mutation in hard endosperm sorghum and its functional properties (pp.561-569). Food Chemistry, 271, USA. doi:Food Chemistry.

Expanding markets for sorghum and millet farmers in West Africa through strengthening of entrepreneur processors and nutrition-based promotion of products
Led by Dr. Bruce Hamaker – Purdue University)

Location (department level)
Niger - Niamey, Tera, Tchirozerine, Magaria
Senegal - Dakar
Burkina Faso - Kaya

Description
This project expands activities with entrepreneurial processors at local incubation centers to develop strategies to fabricate new extruded products, innovative ways to promote processed sorghum and millet products, and nutrient fortification of food products through sustained market demand. The specific project objectives include:

1) To further develop and optimize food items made from sorghum and millet for market expansion with a focus on high quality flour-based and agglomerated products, and newly developed technology for the production of nutritionally-enhanced extruded instant flours for thin porridges target at infant/young children.
2) To strengthen the capacity of Senegalese and Nigerien micro-, small- and medium-sized agribusinesses through existing incubation centers and to identify development partners for business management training and assistance to entrepreneurs, through improved branding, marketing and promotional activities.
3) To leverage nutritional factors in marketing and promotion of sorghum and millet products in rural and urban centers.
4) Integrate with other actors in the value-chain to benefit smallholder farmers through development of output markets.

While addressing the area of inquiry, "Development of added-value products and market development," the research team aims to create successful models using food and nutrition-related technologies to expand markets and improve nutrition and health of vulnerable groups. Scientific and technological research is being used to generate advancements in sorghum and millet utilization while capacity building is incorporated through short-term and graduate degree training.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change. In addition, this project also supports *Objective II: Incubate and nurture a new wave of feed and food products to stimulate demand for sorghum and millet thereby extending economic benefits beyond the farmgate into the broader population* and *Objective III: Create an economically rationalized business and research investment plan to leverage USAID core financing and attract associate awards and broader donor support.*

Collaborators

U.S. collaborating institution(s):	Purdue University
Intl. collaborating institution(s):	*Senegal* - ISRA, CNRA, ITA
	Niger - INRAN

Achievements
In Senegal, extruded instant millet flour was successfully used in combination with binding agents (maltodextrin, xanthan gum) to process arraw, a popular agglomerated product. Tests showed a substantial decrease in arraw production time. Also, cooking times were reduced for the two arraw diameters: from 24 to 10 min for the 2 mm diameter and from 35

to 15 min for the 4 mm diameter products. Prototype products were shown to a major entrepreneur processor in Dakar and high interest was expressed. Optimization studies are in process.

Also, at ITA, fortified instant whole grain millet products were formulated and sensory studies were begun on understanding how whole grain products can be made acceptable to the Senegalese urban consumer, who are not accustomed to whole grain foods. Work on "economic couscous" a less energy intensive and lower cost couscous process developed in the last years of the INTSORMIL project, was advanced with studies on fermented economic couscous using Lactobacillus strains developed by ITA with the Wallonie region cooperation (Gembloux, Belgium). Dakar millet processors working with ITA and the SMIL project see a good market for such a fermented couscous product and the necessary consistency and quality can be obtained using a pure culture fermentation. Also, there appears to be a good market for such a product in the Senegalese diaspora in Europe and North America. Six samples of fermented economic couscous were tested for sensorial acceptability using 85 panelists. Fermentation level, taste, and overall acceptability were measured. Fermented couscous samples 1 and 6 had high acceptability and taste/fermentation level.

In Niger in partnership with the McKnight Foundation project, the Dakoua fortified product developed last year (millet, tigernut, peanut, and other nutrient-rich plant materials) is now processed by rural women trained at the rural food innovation centers who are selling the product as a nutritious snack to primary school children in Tera, Falwell, and Maradi. Fortified products made using moringa, baobab fruit, carrot, and pumpkin as natural fortificants mixed with millet flour are currently being sold by the rural women associations operating in the same food innovation centers. They also are selling these fortified products to patients from the local government health centers. Some of the health centers have expressed the intention to have small stores set up inside the health centers for the women to sell their low-cost fortified products to mothers having undernourished or malnourished children.

In urban areas of Niger, processors were trained in distribution and promotion of extruded products as part of the preparations for the market study. A number of meetings were held to refine the questionnaires for the market study. These address questions of household consumer preference, perception of the instant thin and thick porridge millet products, and repeat purchase at the points of sale. For the first part of the 2-part market study, 330 packets of 500 g of instant *fura* were placed in the same number of households accompanied by a questionnaire; and 280 packets of 500 g of instant thick porridge were distributed. For the second sales part of the market study, 1 ton of products, both instant *fura* and thick porridge, have been produced for testing, expected to start in October 2018 (and completed in January 2019).

Capacity building

Individuals trained under this project include:

Abdourahmane Diop	Universite de Thies	Master's	Agricultural Economics
Aminata Diouf	ITA	Master's	Agricultural Economics
Hawi Debelo	Purdue University	Ph.D.	Food science
Eliasse Dieme	Cheikh Anta Diop University/ITA	Ph.D.	Microbiology
Maty Diop	Cheikh Anta Diop University	Ph.D.	Food Science and Nutrition
Anna Hayes	Purdue University	Ph.D.	Food Science and Nutrition
Moustapha Moussa	INRAN	Ph.D.	Food Science

Lessons learned

Study on product attributes and packaging has determined that urban consumers place the greatest value on knowing the expiration date of the product and knowing that it is locally made. There was less value placed on micronutrient fortification. Processors are highly interested in developing extruded products.

Presentations and publications

Cisse, F., Erickson, D., Hayes, A., Opekun, A., & Nichols, B. (January 2018). Traditional Malian Solid Foods Made from Sorghum and Millet Have Markedly Slower Gastric Emptying than Rice, Potato, or Pasta (pp.124). Nutrients, 10, Zurich, Switzerland. doi:10.3390/nu10020124.

Debelo, H., Ndiaye, C., Hamaker, B., & Ferruzzi, M. (April 2018). Native African plant materials modify delivery of provitamin A carotenoids from blended millet products as assessed by a coupled in-vitro digestion Caco-2 human intestinal cell model. American Society of Nutrition, Boston, United States.

Debelo, H., Ferruzzi, M., & Novotny, J. Nutrient Information Brief for Vitamin A. Advances in Nutrition. In Press. 2017. Advances in Nutrition.

Dieme, E., Sarr, I., Traore, D., & Seydi, M. Critical points of aflatoxin contamination of harvested and stored maize by farmers in Velingara, Senegal. Draft.

Dieme, E., SARR, I., Traore, D., & Hamaker, B. R. (April 2018). Managing aflatoxin contents in cereals and their byproducts in Senegal. Presentation at Sorghum 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town/South Africa.

Diop, M., Traore, D., & Hamaker, B. R. (April 2018). Development of instant flours made from local Senegalese products by extrusion cooking. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Diop, A., Toure, K., Traore, D., & Dalton, T. (April 2018). Analysis of sorghum and millet value chains in Senegal to improve the nutrition status of the populations. Presentation at Sorghum in the 21th Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Diouf, A., Traore, D., & Hamaker, B. R. (April 2018). A review on selected whole grain cereals: Sorghum, millet and fonio. Sorghum in the 21st Century: Food, feed, and fuel in a rapidly changing world, Cape Town, South Africa.

Moussa, M., Hamaker, B. R., A. P., & Campanella, O. (April 2018). Innovative way of making millet couscous by using a single screw mini-extruder for West African market. Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape, Town.

Moussa, M. & Hamaker, B. R. (April 2018). Hub-and-spoke food innovation model empowers rural women to drive markets and improve nutrition in West Africa Hub-and-spoke food innovation model empowers rural women to drive markets and improve nutrition in West Africa. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town.

Moussa, M. & Hamaker, B. R. (November 2017). Food innovation model in West Africa to empower women and youth, and to improve nutrition via fortification and expand market of cereal and legume grain in West Africa. High Level Ministerial Dialogue and Post-Harvest Losses Reduction and Agro-Processing Flagship, Abidjan, Côte d'Ivoire.

Moussa, M., Bugusu, B., & Hamaker, B. R. (July 2018). Food Processing Innovation Models in West and East Africa. Presentation at Borlaug Fellow/Young Entrepreneurs Summer Workshop, Morgan, Entrepreneurship Building Purdue Univ.

Moussa, M., Hamaker, B. R., A. P., & Campanella, O. (2018) Innovative way of making millet and sorghum couscous by using a single screw mini-extruder. Poster at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapidly Changing World.

Moussa, M., Hamaker, B. R., & Bugusu, B. (August 2018). Hub-and-Spoke Food Innovation. Presentation at Lunch of Hub-and-Spoke Food Innovation Project in Kenya and Tanzania supported by Rockefeller Foundation, Kenya, Nairobi.

Moussa, M., Hamaker, B. R., & Bugusu, B. (September 2018). Hub-and-Spoke Food Innovation Scale up. Scale-Up Conference, Purdue University.

Moussa, M. & Hamaker, B. R. (September 2018). Hub-and-Spoke Food Innovation in West Africa. Presentation at 2018 West Africa Regional Pearl Millet Convening, Thies, Senegal.

Associate award project reports

FTFIL for Genomics-Assisted Sorghum Breeding

Award number: AID-OAA-LA-16-00003

(Led by Dr. Geoffrey Morris – Kansas State University, Dr. Gael Pressoir – CHIBAS, and Dr. Ed Buckler – Cornell University)

Description

Globally, there is great interest in applying new genomic technologies to accelerate genetic gains in developing country breeding programs. However, these methods have not been adopted in developing country level National Agricultural Research Institutes (NARI) due a mismatch between available genomic selection approaches and the existing operations of NARI breeding programs. This project aims to develop genomic approaches from within a NARI breeding program to reduce barriers for adoption. Specifically, these improved genomics selection approaches will be deployed to address several key constraints for dual-purpose sorghums used by smallholders in Haiti. The targets will be improving grain yield while maintaining forage yield and quality, improving tolerance to low/high pH soils, and improving tolerance to post-emergence and post-flowering water limitation.

By designing genomics-assisted breeding approaches in a NARI, the resulting technology will be better suited for adoption by other NARI globally. The tools and resources developed in this project will facilitate adoption of genomics-assisted breeding by partner programs in West and East Africa and will be diffused globally via breeding informatics initiatives (GOBII and BMS).

Theory of change and impact pathways

All research projects contribute towards *Objective I* of our theory of change. In addition this project also supports *Objective III: Create an economically rationalized business and research investment plan to leverage USAID core financing and attract associate awards and broader donor support.*

Collaborators

U.S. collaborating institution(s): Kansas State University, Cornell University
Intl. collaborating institution(s): *Haiti* – CHIBAS

Achievements

Young breeding programs in developing countries, like the Chibas sorghum breeding program in Haiti, face the challenge of increasing genetic gain with limited resources. Implementing genomic selection (GS) could increase genetic gain, but optimization of GS is needed to account for these programs' unique challenges and advantages. We used simulations to identify conditions under which genomic-assisted recurrent selection (GARS) would be more effective than phenotypic recurrent selection (PRS) in small new breeding programs. We compared genetic gain, cost per unit gain, genetic variance, and prediction accuracy of GARS (two or three cycles per year) versus PRS (one cycle per year) assuming various breeding population sizes and trait genetic architectures. The maximum relative genetic gain advantage of GARS over PRS was 12–88% for oligogenic architecture with high heritability and 26–165% for polygenic architecture with low heritability. Average prediction accuracy declines substantial after several cycles of selection, suggesting the prediction models should be updated regularly. Updating prediction models every two or three cycles increased the genetic gain compared to no-update scenarios (by up to 39% or 33%, respectively). For small populations and oligenic traits, cost per unit gain was lower in PRS than GARS. However, with larger populations and polygenic traits cost per unit gain was up to 67% lower in GARS than PRS. Collectively, the simulations suggest that GARS could increase the genetic gain in small young breeding programs by accelerating the breeding cycles and enabling evaluation of larger populations.

We have showed that Stay Green is a major component of both stem sugar yield and grain yield (particularly under water stress). The weight of green (and physiologically functional) leaves after grain maturity needs to be a major selection target in order to make progress on stem sugar and grain yields simultaneously. Green leaves allow to continue to accumulate stem sugars after grain filling and grain maturity. Therefore, progress on the traits will depend on predictive ability and selection intensity. Our simulation results (Kebede et al 2018) show that genomic selection should outperform conventional selection in both speed and cost.

Capacity building

Individuals trained under this project include:

Charles Rigaud	CHIBAS	Master's	Genetics
Sarah Jensen	Cornell University	Ph.D.	Plant breeding and genetics

Lessons learned

Shipping DNA, tissue, and some reagents into Haiti has been challenging. We have developed a number of strategies to make this more efficient, and are hoping these efforts will make the first round of genomic selection go smoothly. Long term, we will work to reduce the number of shipping exchanges needed between the U.S. and Haiti.

Presentations and publications

Charles, R. J. (2018) Caractérisation et évaluation des prédictions génomiques des lignées de sorgho développées par le Chibas en Haïti.

Charles, J., Morris, G. P., Muleta, K. T., & Pressoir, G. H. (April 2018). Factors affecting accuracy for genomic prediction in sorghum. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel for a Rapid Changing World, Cape Town, South Africa.

Charles, J., Muleta, K. T., Morris, G. P., & Pressoir, G. H. (January 2018). P0880 Genomic prediction and genetic diversity in a sorghum population undergoing simultaneous selection for grain and stem sugar yields. Plant and Animal Genome XXVI Conference, San Diego, CA, USA.

Charles, J., Muleta, K. T., Morris, G. P., & Pressoir, G. H. (January 2018). P0889 Newly developed melanaphis-resistant sorghum lines in Haiti show a strong selective sweep at a locus on chromosome 6 collocated with the known RMSE1 gene. Plant and Animal Genome XXVI Conference, San Diego, CA, USA.

Charles, J., Pressoir, G. H., Muleta, K. T., & Morris, G. P. (April 2018). Newly developed melanaphis-resistant sorghum lines in Haiti show a strong selective sweep at a locus on chromosome 6 collocated with the known RMSE1 gene. Presentation at Sorghum 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Jensen, S. E. (2018) Genomic prediction with the sorghum Practical Haplotype Graph (PHG).

Jensen, S. E., Ramu, P., CHARLES, J., Ramstein, G., Buckler, E., Morris, G. P., & Pressoir, G. H. (April 2018). From Seed to Selection: Tools for quick and cost-effective genomic prediction in sorghum. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Jensen, S. E., Ramu, P., Miller, Z., Wang, X., Muleta, K. T..... (2018) Making predictions from seed to selection: Tools for quick and cost-effective genomic prediction in sorghum. Poster for Sorghum in the 21st Century: Feed, Food and Fuel in the 21st Century.

Muleta, K. T., Buckler, E., Pressoir, G. H., & Morris, G. P. (January 2018). P0846 Optimizing genomic-assisted recurrent selection for small breeding programs in developing countries. Plant and Animal Genome XXVI Conference, San Diego, CA, USA.

Muleta, K. T., Pressoir, G. H., & Morris, G. P. Optimizing genomic selection for a sorghum breeding program in Haiti. G3. Under review.

Pressoir, G. H., Charles, J., Jensen, S. E., Buckler, E., Muleta, K. T., & Morris, G. P. (April 2018). Increasing the rate of genetic gain through the use of genomic selection in a low resource breeding program. Presentation at Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World, Cape Town, South Africa.

Pressoir, G. H., Charles, J., Muleta, K. T., Buckler, E., & Morris, G. P. (January 2018). P0847 Making genomic selection possible in low-resources breeding programs. Plant and Animal Genome XXVI Conference, San Diego, CA, USA.

Morris, G. P., Pressoir, G., & Muleta, K. T. Optimizing genomic selection for a sorghum breeding program in Haiti - a simulation study. G3: Genes, Genomes, Genetics. Under review.

Muleta, K. T., Pressoir, G. H., & Morris, G. P. (January 2018). Optimizing genomic-assisted recurrent selection for small breeding programs in developing countries. Plant and Animal Genome (PAG), San Diego.

Human and Institutional Capacity Development

As in previous years, human and institutional capacity development was prioritized in the Lab, which resulted in important progress being made in the area, most notably in human capacity development.

Short-term training

In FY 2018, the Sorghum and Millet Innovation Lab again surpassed the anticipated target number of short-term trainees by more than 700 individuals. Across all projects, the Lab trained a total of 2,081 individuals, including 708 males and 1,373 females.

Of the more than 2,000 trainees, producers made up the largest group with 1,685 trained, followed by 204 civil society members (predominantly researchers and students), 88 people in government, 22 in private sector firms and 82 unknown.

The types of short-term trainings conducted varied, and included farmer trainings, professional workshops, on-the-job capacity-building exercises and academic courses. One project in particular accounted for the largest percentage of all short-term trainees by training approximately 1,180 producers in Niger via a farmer training on seedball production and testing. Another large training that included 345 individuals in Niger was on food product fortification.

Table 1. Short-term trainees supported by the Sorghum and Millet Innovation Lab – FY 2018

Country of Training	Purpose of Training	Who was trained	Number trained		
			M	F	Total
Ethiopia	Approaches to disease resistance phenotyping in disease nurseries	Government: 4	4	0	4
Ethiopia	Hybrid sorghum seed production method	Producers: 10 Government: 8 Private sector: 2 Unknown: 50	65	5	70
Mali	Participative selection of double-usage varieties in the Cinzana commune	Producers: 15 Government: 4	13	6	19
Niger	Hands-on training on drought phenotyping in lysimeter system	Civil society: 1	1	0	1
Niger	Rearing of Habrobracon hebetor parasitoids by farmers' cooperatives	Producers: 18	16	2	18
Niger	One-day scientific conference on sorghum entomology and breeding results	Producers: 1 Government: 53	34	20	54

Niger	Short training to urban processors on processing, marketing and distribution, and data collection on instant millet flours for making thick porridge ("tuwo") and beverage ("fura") in urban Niamey	Producers: 25 Government: 2 Private sector: 5 Civil society: 11	31	12	43
Niger	Training on cereal-legumes fortification using natural rich mineral (moringa, boabab) and vitamin A (carrot, pumpkin/squash) and data collection	Producers: 330 Government: 4 Private sector: 1 Civil society: 10	20	325	345
Niger	McKnight Foundation/Community of Practice for the West Africa Collaborative Crop Research Program	Producers: 5 Civil society: 52	44	13	57
Niger	Seedball production technique, animators	Civil society: 40	36	4	40
Niger	Seedball production, producers	Producers: 1176	279	897	1176
Niger	Farmer exchange on seedball production	Civil society: 4	2	2	4
Niger	Discussions with Kouria Peulh farmers about their preferred traits in pearl millet varieties (including dual purpose ones) selection	Producers: 100 Government: 3 Civil society: 2	84	21	105
Senegal	Introduction to genomics enabled breeding	Civil society: 15	6	9	15
Senegal	Short training of two urban area enterprises (Free Work Service and Maria Distribution) on instantizing their existing formulated products for ready-to-eat products	Government: 1 Private sector: 12	5	8	13
Senegal	Training of the Diourbel region platform on the enriched millet flours with local plant materials	Producers: 5 Government: 1 Private sector: 2 Unknown: 32	10	30	40
U.S.	Buckler Lab Hackathon – January 2018	Government: 2 Civil society: 17	13	6	19

U.S.	Practical Haplotype Graph (PHG) Workshop	Government: 3 Civil society: 37	31	9	40
U.S.	Buckler Lab Kotlin Programming School 2018	Government: 3 Civil society: 15	14	4	18

Long-term training

In FY 2018, the Lab again saw an increase in total numbers of long-term trainees. The program now has a total of 68 different trainees, six of which are new to the program's roster this year. Among those 68 trainees, 46 are male and 22 are female. The group also represents a variety of degree levels with two agricultural engineers, five Bachelor degrees, 30 Master degrees, 30 Ph.Ds. and one post-doc.

Table 2. Long term trainees supported by the Sorghum and Millet Innovation Lab – FY 2018

Last name	First name	Sex	University	Degree	Major	Graduation date	Degree granted?	Home Country
Boubacar	Siby	Male	Universite Prive de Segou Agri SUP	Bachelor's	Agronomy	Dec-18	No	Mali
Diao	Aissatou	Female	CERAAS	Bachelor's	Agronomy	Jan-17	Yes – Pursuing Master's degree at University Cheikh Anta Diop	Senegal
Ousseini	Iro	Male	INRAN	Bachelor's	Agronomy	Nov-17	Yes	Niger
Thiam	Anna	Female	CERAAS	Bachelor's	Agronomy	Jan-17	Yes – Searching for employment	Niger
Assoumane	Sidi	Male	ICRISAT – Niger	Bachelor's	Ecophysiology	Dec-18	No	Niger
Kasse	Mame More	Male	ISFAR/University of Thies	Engineer	Agricultural Engineering	Jul-17	Yes – on an internship with an agricultural entreprise	Senegal
Sarr	Adama	Female	ISFAR/University of Thies	Engineer	Agricultural Engineering	Jul-16	Yes – has been recruited by agricultural firm, SODAGRI	Senegal
Abassa	Daouda	Male	INRAN	Master's	Socio-economy	Jan-18	Yes	Niger
Adane	Getahun	Male	Hawassa University	Master's	Food science and postharvest technology	Feb-18	Yes	Ethiopia
Bekele	Alemnesh	Female	Haramaya University	Master's	Plant pathology/breeding	May-18	Yes	Ethiopia
Berhanu	Chemeda	Male	Haramaya University	Master's	Plant pathology/breeding	Oct-17	Yes	Ethiopia

Dieng	Cheikh	Male	Ecole National Superieure d'Agriculture (ENSA)	Master's	Production Végétales	Jan-16	Yes – currently farming but awaiting near-term appointment from national research program	Senegal
Diome	Mouhamadou	Male	ENSA Thies	Master's	Socio-economy	Dec-17	Yes	Senegal
Diouf	Aminata	Female	ITA	Master's	Agricultural Economics	May-16	Yes	Senegal
Idrissa	Hamidou	Male	Université Abdou Moumouni de Niamey	Master's	Entomology	Jan-18	Yes	Niger
Illiassou	Abdou	Male	Universite Dan Dicko Dankoulodo	Master's	Agronomy	Dec-17	Yes	Niger
Kane	El Hadj Malick	Male	CERAAS	Master's	Microbial and vegetal biotechnology	Sep-17	Yes	Senegal
Kassie	Mengistu	Male	Kansas State University	Master's	Agricultural Economics	Dec-18	No	Ethiopia
Kandji	Omar	Male	University Cheikh Anta Diop	Master's	Pest Management	May-17	Yes – on an internship with AGRA; looking for Ph.D. funding	Senegal
Laminou	Said	Male	Université Abdou Moumouni de Niamey	Master's	Entomology	Jan-18	Yes	Niger
Ly	Marietou	Female	ENSA/University of Thies	Master's	Sustainable development and society/agriculture	Aug-17	Yes – searching for Ph.D. funding	Senegal
Maazou	Mahamadou	Male	University of Tahoua	Master's	Socio-economy	Dec-17	Yes	Niger
Ouedraogo	Benoit	Male	University of Ouagadougou	Master's	Breeding and conservation of seed	Apr-17	Yes	Burkina Faso
Rigaud	Charles	Male	CHIBAS	Master's	Genetics	Nov-17	Yes	Haiti
Thiam	Baye	Male	University of Thies	Master's	Agricultural engineering	Apr-17	Yes	Senegal
Zongo	Rachelle Yvonne	Female	INERA	Master's	Seed selection and conservation (SELCOSE)	Dec-15	Bachelor's granted, now working on Master's	Burkina Faso
Diop	Abdourahmane	Male	Universite de Thies	Master's	Agricultural Economics	2017	Yes – works as consultant to NGO Terre des Hommes and on East African Media Lab project	Senegal

Dessalgn	Kebede	Male	Haramaya University	Master's	Plant pathology/breeding	Dec-15	Yes – works for BAKO Research Center at Oromia Research Institute	Ethiopia
Gbedié	Nadre	Male	CERAAS	Master's	Breeding	Apr-16	Yes – currently applying to DADD fellowship program for Ph.D.	Côte d'Ivoire
Guerci	Michael	Male	Virginia Tech	Master's	Agricultural Economics	May-16	Yes – works (volunteers) for U.S. Peace Corps in the Philippines	United States
Mengistu	Loza	Female	Hawassa University	Master's	Food Processing and Preservation	Mar-17	Yes – now employed at a private company	Ethiopia
Moumouni	Oumou	Female	Abdou Moumouni University of Niamey with Short Training at Virginia Tech	Master's	Agricultural Economics	Jan-18	Yes	Niger
Sene	Gnilane	Female	University Cheikh Anta Diop	Master's	Pest management	Dec-15	Yes – recruited by agricultural enterprise	Senegal
Abduselam	Fuad	Male	Haramaya University	Master's	Agronomy	Jul-16	Yes - now working for Oromia Agricultural Research Institute, Fedis Research Center	Ethiopia
Aidara	Kader	Male	ISRA	Master's	Agroforestry ecology and adaptation	Nov-18	No	Senegal
Sy	Anta	Female	ISRA	Master's	Analytical Chemistry	Jul-18	Yes - under consideration for a Ph.D., in training at biochemistry lab at CERAAS	Senegal
Amadou	Laouali	Male	University of Maradi	Ph.D.	Entomology	Jan-19	No	Niger
Atchozou	Eyanawa Akata	Male	CERAAS	Ph.D.	Agronomy (Breeding & Genetics)	Jan-18	Yes – returned to Togo to continue work on his research program	Togo

Bayable	Demeke	Male	Purdue University	Ph.D.	Plant pathology	Aug-19	No	Ethiopia
Belayneh	Yemane	Male	Kansas State University	Ph.D.	Plant breeding and genetics	Dec-19	No	Ethiopia
Chere	Diriba Hika	Male	Kansas State University	Ph.D.	Plant pathology/breeding	Dec-20	No	Ethiopia
Debelo	Hawi	Female	Purdue University	Ph.D.	Food science	Aug-18	No	Ethiopia
Diatta	Cyril	Male	CERAAS	Ph.D.	Plant breeding and genetics	Dec-19	No	Senegal
Diatta	Elizabeth	Female	West African Center for Crop Improvement	Ph.D.	Plant Breeding	Dec-18	No	Senegal
Dieme	Eliasse	Male	Cheikh Anta Diop University/ITA	Ph.D.	Microbiology	Jul-18	No	Senegal
Diop	Maty	Female	Cheikh Anta Diop University	Ph.D.	Food Science and Nutrition	Jul-18	No	Senegal
Faye	Jacques	Male	Kansas State University	Ph.D.	Agronomy (Plant Breeding & Genetics)	Dec-18	No	Senegal
Goudiaby	Mame Fatoumata	Female	University Cheikh Anta Diop	Ph.D.	Entomology	Dec-17	No	Senegal
Griebel	Stephanie	Female	Purdue University	Ph.D.	Agronomy	Dec-18	No	Germany
Hayes	Anna	Female	Purdue University	Ph.D.	Food Science and Nutrition	Aug-19	No	USA
Jensen	Sarah	Female	Cornell University	Ph.D.	Plant breeding and genetics	Aug-21	No	USA
Kadi Kadi	Hame Abdou	Male	West Texas A&M University	Ph.D.	Plant, Soil and Environmental Science - Insect Pest Management	Jul-18	No	Niger
Karimoune	Laouali	Male	ICRISAT – Niger	Ph.D.	Entomology	Dec-19	No	Niger
Maina	Fanna	Female	Kansas State University	Ph.D.	Agronomy (Plant Breeding & Genetics)	May-18	No	Niger
Mezgebe	Abadi	Male	University of Pretoria	Ph.D.	Food Science	Jul-18	No	Ethiopia
Moussa	Moustapha	Male	INRAN	Ph.D.	Food Science	May-19	No	Niger
Nakelse	Tebila	Male	Kansas State University	Ph.D.	Agricultural Economics	Jul-18	No	Burkina Faso
Nida	Habte	Male	Purdue University	Ph.D.	Plant breeding and pathology	Jun-20	No	Ethiopia
Nwankwo	Charles	Male	University of Hohenheim	Ph.D.	Agriculture	Jun-17	Yes – continues to work in research at University of Hohenheim	Nigeria
Ongom	Patrick	Male	Purdue University	Ph.D.	Plant Genetics	May-16	Yes – works at Makerere University in Uganda	Uganda
Seyni	Ousmane	Male	West African Center for Crop Improvement	Ph.D.	Plant Breeding	Dec-18	No	Niger
Teferra	Tadesse	Male	Texas A&M	Ph.D.	Food Science	Dec-18	No	Ethiopia
Thiam	Adja	Female	University of Thies	Ph.D.	Pest management	Dec-17	No	Senegal

Welle	Fatou	Female	University Cheikh Anta Diop	Ph.D.	Pest management	Dec-17	No	Senegal
Xu	Xiaochen	Male	Purdue University	Ph.D.	Plant breeding and genetics	May-19	No	China
Olatoye	Marcus	Male	Kansas State University	Ph.D.	Plant breeding and genetics	Dec-17	Yes - currently a crop genetics post-doc at the University of Illinois	Nigeria
Geiger	Lena	Female	INRAN	Ph.D.	Agronomy/Soil science	Feb-19	No	Niger
Adeyanju	Adedayo	Male	Purdue University	Post-doctoral Studies	Plant Genetics	Jun-17	Yes	Nigeria

Numerous students trained under Sorghum and Millet Innovation Lab support received awards of recognition for their accomplishments during FY 2018. Some of these awards include:

- *2018 BIFAD Award for Scientific Excellence in a Feed the Future Innovation Lab*
  Laouali Amadou - Université de Maradi - Niger

- *Student Poster Presentation – Sorghum in the 21st Century (2018 Global Sorghum Conference)*
  Fanna Maina - Kansas State University, USA and Institut National de la Recherche Agronomique du Niger (INRAN), Niger

- *People's Choice Award for the Three-Minute Thesis (3MT) - Sorghum in the 21st Century (2018 Global Sorghum Conference)*
  Abdourahmane Diop - Institut de Technologies Alimentaires (ITA), Senegal

Institutional development

The Sorghum and Millet Innovation Lab maintains a strong focus on institutional development in its target countries and beyond. Capacity building occurred on a number of levels, including support for key partner institutions such as CERAAS and INRAN. At CERAAS, the SMIL-supported grain quality laboratory is functioning well and serves an important research function while providing a training platform for students and future scientists. Additionally, the Lab's choice to host the 2018 West Africa Regional Pearl Millet Convening at CERAAS was an important capacity-building activity for the center's administrative staff. The center now has additional regional and international conferences planned as its presence continues to grow. The Lab's relationship with INRAN continues to develop as administrative capacity is strengthened. Strong in-country coordination and communication has led to close and effective processes with the INRAN administration, including support staff all the way to the director general. This allows for quick and efficient communication as the need arises.

Cooperation with our National Agricultural research Institutes (NARI) partners in Senegal, Niger and Ethiopia to strengthen their environmental compliance capacity has continued. The Lab management entity previously coordinated with the existing environmental compliance resource persons/framework, linked key NARI staff to additional USAID-led regional environmental compliance training opportunities, organized cross-learning opportunities in environmental compliance, and introduced a web-based environmental compliance reporting module.

It is our vision to support a strong coordination between the Lab and national partners embedded within the NARI system structure. It was envisioned that country coordinators could take on a strategic role to interface with the much wider sector of development actors and the private industry, identify new partnership and financing opportunities within

the region to enhance impact while working closely with the NARI structures. In Senegal, Niger, and Ethiopia this has led to multiple engagements with the public and private sector to represent the NARI and the Lab/USAID-funded research projects. This has been of particular importance in regards to showcasing technology packages that are ready for uptake into much larger development partner networks.

At the global level, the Sorghum and Millet Innovation Lab contributed to the development of a global sorghum network via the *Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World*. Not only did the initiative allow the Lab to compile a database of some 2,000 contacts in the sorghum industry, the event itself saw the formation of numerous international collaborations and partnerships between individuals and institutions alike.

Additionally, the Lab also helped to facilitate the gelling of a West Africa regional pearl millet network through a convening in early September at CERAAS in Thies, Senegal, and continued support of regional pearl millet research to address key issues impacting smallholders throughout Africa and beyond. These efforts are providing the foundation to support a broader regional network of institutional partnerships and research pathways across the region.

Innovation transfer and scaling partnerships

The Sorghum and Millet Innovation Lab research portfolio is delivering technology packages to the marketplace to address important needs and challenges for smallholders and other end users. At present, the Lab has numerous technologies in process at a phase I (*Under research*), II (*Under field-testing*), III (*Available for scaling*), IV (*Actively being scaled*) levels with other technologies that will continue to develop. Phase III technology packages that are now available for scaling include:

- Registered sorghum germplasm with resistance against the sugarcane aphid for utilization by global breeding teams.
- A white sorghum hybrid with strong yield performance for uptake in lowland production areas of Ethiopia.
- Seed ball formulation, production, and planting techniques to reduce risk and improve yield for pearl millet farmers in the Sahelian zone of West Africa.
- An integrated pest management technology with mass rearing of naturally occurring beneficial parasitoid wasps and timely release at a community level to control the millet head miner in West Africa.

The Lab management entity will continue to play a strategic role to facilitate enabling environments that support the further scaling of technology packages. This will involve broad based partnerships linked to the marketplace and defining pathways to move technology packages to scale. A technology catalog will be developed to feature technology packages available for scaling and will include a description, in-country contacts, reference materials, and where relevant a short introductory video.

Phase I technologies – Under Research

1. Technology: Sorghum germplasm/variety development for food quality

Category: Biological

Area of inquiry: Genetic enhancement

Description and steps taken: Large number of populations, families and advanced breeding lines are being evaluated to select the most promising materials with enhanced agronomic adaptation and nutritional quality for use by smallholder sorghum grower community in Ethiopia. More population will be developed based on genetic and genomic information being generated. Altogether, these will advance sorghum research for enhanced protein nutrition and along with other nutritional programs will contribute to improved health and productivity of communities who rely on sorghum as primary source of energy and protein.

Partnerships made: Local partner institutions from three major sorghum growing regions of the country, namely, Amhara Regional Agricultural Research, Institute (Amhara), Oromia Agricultural Research Institute (OARI), Tigray Agricultural Research Institute (TARI) and Haramaya University.

Next steps: Completing field phenotyping and laboratory work on PD and factors surrounding protein availability in sorghum.

Target country: Ethiopia

2. *Technology: Development of parental materials for disease resistance*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Evaluations of diverse sorghum lines for resistance against both grain and foliar diseases are in progress. Once the most promising resistant lines are identified, these traits will be introgressed into locally adapted cultivars to produce parental materials for the development of adapted disease-resistant lines.

Partnerships made: Local partner institutions from major sorghum growing regions including Asosa, Pawe and Bako research centers (EIAR) and Holleta Biotechnology Center.

Next steps: Continue screening activities for further evaluation of disease resistance. Some of the very promising disease resistance lines are being crossed into the locally adapted material with the goal of generating segregating population that will be further selected for disease resistance as well as other agronomic traits.

Target country: Ethiopia

3. *Technology: Experimental hybrids for commercial sorghum seed industry*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Seventy-two experimental hybrids (out of a pool of 164) were advanced for continued evaluation at multiple locations.

Partnerships made: Local partner institutions including Melkassa and Sirinka research centers (EIAR), and Holleta Biotechnology Center, Tigray Regional Program, Oromia Regional Program and Haramaya University.

Next steps: Continue screening activities for further hybrid evaluation

Target country: Ethiopia

4. *Technology: Genomics-enabled breeding platform*

Category: Management Practices

Area of inquiry: Genetic enhancement

Description: The genomics-enabled breeding platform will include a genomic diversity database of West African germplasm (traditional varieties and breeding material), analysis tools for identifying useful genetic markers based on genomic diversity data, diagnostic genetic markers for useful traits and the locally-preferred genetic background, and network of trained geneticists and breeders that can take advantage of these resources in crop improvement.

Partnerships made: The team anticipates establishing partnerships with the Integrated Breeding Platform based at CIMMYT and the CGIAR Genomics Back Office based at Cornell University (when launched).

Next steps: In the coming year the team will analyze the genomic diversity data (genotyping-by-sequencing) for the West African Sorghum Association Panel, and the U.S.-based collections of Senegalese and Nigerian

germplasm. They will identify and test new genetic markers for drought-related and locally-preferred genetic backgrounds.

Target countries: Senegal and Niger

5. *Technology: Locally-preferred sorghum varieties with improved adaptive traits*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Our goal is to further the development of several new locally-improved sorghum varieties. These will have locally-preferred genetic backgrounds with additional adaptive traits (drought tolerance, mold resistance, striga resistance) introgressed from other regional or international germplasm sources.

Partnerships made: In the final stage of the project, when new varieties have been developed and are ready for initial field testing, it is anticipated that the project team will partner with the Senegalese farmer cooperative RESOOP (Le Réseau des Organisations Paysannes et Pastorales du Sénégal), current partners of project co-PI Ndiaga Cisse for field testing, seed production, and marketing.

Next steps: The team will continue marker-assisted recurrent selection of existing breeding populations at CERAAS, and continue the early generation population development for new breeding populations at INRAN.

Target countries: Senegal and Niger

6. *Technology: Food quality traits in sorghum*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Parental materials consisting of crosses of elite West Africa breeding lines with mutants having high protein digestibility have been generated. This platform has allowed for the advancement of 11 additional breeding populations to the F3 generation.

Partnerships made: ITA, CERAAS, ISRA, CNRA, INRAN

Next steps: Continue screening activities for further evaluation of food quality traits.

Target countries: Senegal and Niger

7. *Technology: Forage digestibility traits in sorghum*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Parental materials consisting of crosses of elite West Africa breeding lines with mutants having BMR traits have been generated. Two new populations derived from crosses with N223 that were sent to INRAN.

Partnerships made: ITA, CERAAS, ISRA, CNRA, and INRAN

Next steps: Continue screening activities for further evaluation of forage digestibility.

Target country: Niger

8. *Technology: Best dual-purpose genotypes selected by country*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Several genotypes have been selected as having the most dual productivity (grain and straw yield) in Burkina Faso (19), Mali (20), Niger (40) and Senegal (34). The main characteristics being observed in these selections include spikelet length (LOE), plant height (HTR), spikelet width (LAE) and downy mildew incidence (DM2).

Partnerships made: Research stations of Gampela, Kouaré, Katchari (Burkina Faso), N'Tarla, Cinzana (Mali), Bengou, Kolo (Niger) Nioro, Bambey (Sénegal)

Next steps: Project will continued with seed and stover/forage analysis, breeder seed production, and on-farm participatory selection. The project also plans to incorporate short- and long-training as well as gender implications in activities, including on-farm selection activities.

Target countries: Senegal, Mali, Burkina Faso and Niger

9. *Technology: Food product innovation with new improved sorghum endosperm*

Category: Mechanical and physical

Area of inquiry: Added-value products and markets

Description: Methods to incorporate sorghum in traditional and modern food products without negative impact on sensory quality.

Partnerships made: Pending

Next steps: Form partnerships with local food processors to test the technologies under development. Both processing quality and consumer acceptability will be evaluated.

Target countries: Senegal and Niger

10. *Technology: Development of new sorghum varieties from genomic selection program*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Development of new high-yielding sorghum varieties (for low or no-input environments)

Partnerships made: Early stage of development

Next steps: Variety development and field testing

Target countries: Haiti

11. Technology: Improved and cheaper technology for implementation of genomic selection by breeders in developing countries

Category: Biological

Area of inquiry: Genetic enhancement

Description: Development of <$5 per genotype DNA extraction and genotyping, a DNA extraction and GBS pipeline requiring no lab for the breeder (just marker data). Compilation of a database with the whole genome sequence and imputed data for the entire breeding program as well as the development of a public "open source" training set and genomic-assisted breeding population for multipurpose sorghum varieties (grain and forage). Development of a population for which it would be easy to add new variation in the system (use the base system as a building block to build one's own genomic-assisted breeding program) and an approach to breed for multiple environments (developing/improving the strategy to predict the breeding value across different environments).

Partnerships made: Kansas State University, Cornell University

Next steps: Testing

Target country: Haiti

12. Technology: Identification and characterization of protease inhibitor genes associated with protein digestibility (new)

Category: Biological

Area of inquiry: Genetic enhancement

Description: Protease inhibitors are compounds known to reduce protein digestibility through inhibiting the activity of protein digestive enzymes. Comparison of protein digestibility score before and after protease inhibitor removal in raw sorghum flour samples resulted in stunning difference in digestibility. Progress was made in purifying, characterizing and identifying genes coding for protease inhibitor proteins. Six cysteine protease inhibitors were detected in the samples, four of them (Sobic.001G324500, Sobic.001G324700, Sobic.001G324800 and Sobic.001G487800) on chromosome 1 and two of them (Sobic.003G126800 and Sobic.003G400400) on chromosome 3 of sorghum genome. Markers selectively amplifying these genes were also developed.

Partnerships made: The University of Florida Proteome Facility was a new collaborator that came on board to help detect the protease inhibitor proteins/genes.

Next steps: The next step in this effort should be the use of these markers to screen sorghum genotypes for variants of protease inhibitor genes with reduced activity. Such variants can be used in a breeding program, especially in conjunction with the novel kafirin alleles described earlier in order to develop new sorghum cultivars that carry novel kafirin alleles and allelic variants of protease inhibitor with low inhibitory activity to

enhance protein availability.

Target countries: Ethiopia

13. Technology: Improved food processing methods for enhancing protein digestibility (new)

Category: Management and cultural practices

Area of inquiry: Added-value products and markets

Description: While all food preparation methods reduce protein digestibility, fermented bread (injera) commonly consumed in Ethiopia is less affected by cooking perhaps due to partial breakdown of starch by fermentative enzymes to free proteins or due to the acidic environment created as a result of fermentation. The digestibility of injera can be further enhanced through preprocess treatments such as light roasting, decortication or sprouting and by modifying processing methods such as optimizing fermentation and reducing flour particle size.

Partnerships made: Ethiopian Nutrition Institute

Next steps: Next steps should emphasize on determination of grain physical and chemical properties that specifies their use for making a given food product. Moreover, it is important to conduct a comprehensive analysis of biological value of sorghum and other food crops in order to determine the extent to which low digestibility of sorghum affects nutritional outcomes of communities dependent on this crop.

Target countries: Ethiopia

14. Technology: Marker tools for novel kafirin alleles associated with improved protein digestibility (new)

Category: Biological

Area of inquiry: Genetic enhancement

Description: Novel alleles that were significantly associated with protein digestibility in a range of sorghum cultivars differing for the digestibility trait were discovered. Markers developed to track these alleles in breeding population offer a powerful tool for complementing the traditional breeding approach to accelerate breeding for enhancing protein digestibility and improving nutrition of smallholder farmers dependent on this crop.

Partnerships made: EIAR, Kansas State University, USDA-ARS

Next steps: Several advanced breeding families are under evaluation in Ethiopia and United States and other populations are being developed. These tools can be applied to both the advanced families as well as the early generation population to allow selection of families carrying the desired alleles. One of the key activities in the next phase of the project will be the use of these markers in conjunction with traditional selection methods to allow identification of genotypes that combine improved agronomic values with enhanced protein digestibility.

Target countries: Ethiopia

15. Technology: Use of egg parasitoid Trichogrammatoidae armigera for controlling the head miner (new)

Category: Management and cultural practices

Area of inquiry: Production systems management

Description: The head miner egg parasitoid Trichogrammatoidae armigera is being tested for use as biological control agent in addition to the larval parasitoid. At current stage of research we have successfully established colonies and develop a standard mass culture technique for the parasitoids on factious host Coryra cephalonica. We have collected the parasitoid bionomic data and have started on-station testing for effectiveness.

Partnerships made: We successfully established contact with Egyptian Biological control society who offered training to our staff. This training has been very helpful for our work and has led to the successful establishment of parasitoid colonies in our laboratory.

Next steps: On-farm testing will be needed to validate the potential of the egg parasitoid against the millet head miner. Transfer of the technology to farmers' cooperatives.

Target countries: Senegal and Niger

16. Genetic markers for sorghum breeding programs (new)

Category: Biological

Area of inquiry: Genetic enhancement

Description: Developing breeder-friendly genetic markers to facilitate selection of agronomic traits, including sugarcane aphid resistance, stem juiciness, and maturity

Partnerships made: Chibas, Cornell, USDA-ARS

Next steps: Continuing development of markers, testing in predict

Target countries: Senegal and Niger

Phase 2 technologies – Under Field Testing

1. Technology: Seedball fabrication mechanization for men with mediocre investment capital

Category: Mechanical and physical

Area of inquiry: Production systems management

Description: Men will only invest in seedball technology if working time demand is relatively low. Therefore, a mechanical device was constructed that can serve interested men as well as small local seed enterprises. The device allows for a throughput of several thousand seedballs per hour at medium (in the local sense) investment costs.

Partnerships made: Fleischle GBR, Vaihingen Enz - Germany

Next steps: The mechanisation option has shown to work under farmers' condition. However, local craftsmen were not able to copy it. It appears unlikely that the technology presented is worth investment. Much higher throughput per time is requested that can only be achieved by a motorized and more automated technology as used e.g. by Fleischle GBR. At the time being, independent efforts to mechanize seedball production are underway: https://seedtheglobe.com/en/platform.html

Target countries: Senegal and Niger

2. *Technology: Seedball fabrication mechanization for women with low investment capital*

Category: Mechanical and physical

Area of inquiry: Production systems management

Description: The technology is based on an easy to construct frame that produces about 80 seedballs in one batch. It is designed in particular for women with low investment capital that need to sow more than a home garden surface.

Partnerships made: Fleischle GBR, Vaihingen Enz - Germany

Next steps: The mechanisation option has shown to work under farmers' condition. However, local craftsmen were not able to copy it. Therefore, modifications need to be developed with craftsmen and farmers together, also in order to increase productivity. The presented tool did not sufficiently reduce number of seedballs produced per unit time.

Target countries: Senegal and Niger

3. *Technology: Improved endosperm sorghum for protein quality and processing functionality*

Category: Biological

Area of inquiry: Added-value products and markets

Description: Combining high digestible, high lysine sorghum trait with modified starch profile (waxy trait) to improve sorghum functionality as a food ingredient in traditional and modern processes in Ethiopia. This will result in higher food use of sorghum and thus higher crop value for small scale farmers. The high lysine trait will also improve nutritional status in children.

Partnerships made: None yet established

Next steps: Evaluating performance of the improved sorghums in various environments in Ethiopia.

Target country: Ethiopia

4. *Technology: Extruded sorghum- and millet-based food products*

Category: Mechanical and Physical

Area of inquiry: Added-value products and markets

Description: Formulas for extruded sorghum- and millet-based products that incorporate local plant products for the purpose of nutrient fortification have been developed. These formulations are being utilized in extruded infant cereal production.

Partnerships made: Moribeen/Western Niger (Tillabery and Dosso) and Fuma Gaskiya/Eastern Niger (Maradi), McKnight Foundation, ISRA, CNRA, INRAN

Next steps: Continue testing on the products for nutrient delivery efficiency as well as product consumer feedback

Target countries: Senegal and Niger

5. *Technology: Development of rural incubation centers*

Category: Management practices

Area of inquiry: Added-value products and markets

Description: In joint work with the McKnight Foundation in Niger and Burkina Faso, the management structure and engagement approach with rural processors has been developed and the functioning is being continually refined.

Partnerships made: Partnerships have been well established with rural women processors and associations. The team is also in discussion with other donors, including the World Bank, the German government and a local Nigerien USAID project (REGIS).

Next steps: Currently in discussions on possibility of scale-up of these activities.

Target countries: Senegal and Niger

6. *Technology: 120 dual-purpose pearl millet varieties selected and in farmer fields for participatory selection*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Two years of on-station research has given the opportunity to breeders across the four West African countries (Senegal, Burkina Faso, Mali and Niger) to identify 120 dual-purpose varieties with both good grain and fodder yield as well as quality. These varieties are being planted as a part of on-farm trials to select the best varieties from farmer and breeder feedback and observations. The breeders' seed was multiplied to produce the necessary seed for farmer trials – this provided the opportunity for farmers to learn good pearl millet cropping and seed multiplication techniques.

Partnerships made: Primarily with farmer organizations and NGOs, including Burkina Faso organizations/institutions of FEPAB (Katchari, Boulsa and Toma), the agricultural ministry (Kokologo), AGRISEM (Kaya), COPROSEL (Pobe Mengao) and FAGRI (Dedougou)

Next steps: Identify 3-5 dual-purpose varieties by farmers this season and confirm them during the 2018 rainy season. Produce breeder seed to meet farmer's needs and produce foundation seed to meet farmer needs.

Target countries: Senegal, Mali, Burkina Faso and Niger

7. *Technology: Insect-resistant sorghum cultivars*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Sorghum germplasm consisting of insect-resistant lines are being developed. The germplasm also should have resistance to other biotic stresses.

Partnerships made: ISRA, CNRA, CERAAS, INRAN

Next steps: Use sorghum germplasm in a breeding program and transfer resistant lines.

Target countries: Senegal and Niger

8. *Technology: Evaluation of technologies to manage insect pests of sorghum*

Category: Management practices

Area of inquiry: Production systems management

Description: Developing and evaluating approaches to manage biotic and abiotic stresses in the field, storage, and laboratory without relying on pesticides.

Partnerships made: INRAN, CNRA, CERRAS, ISRA

Next steps: Complete the identification and transfer of the best technologies such as botanicals, double hermetic bagging, resistant sorghum lines, and inexpensive traps to monitor and control insect pests at the farm level and in storage facilities.

Target countries: Senegal and Niger

9. *Technology: Broad spectrum disease-resistant sorghum lines (new)*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Disease nurseries were conducted to identify disease resistant materials derived from local germplasm and genetic studies at Purdue in the PIs and his collaborators laboratory. These analyses identified sorghum germplasm to lay the foundation for rigorous selection of materials to be released as varieties in the disease-prone regions in Ethiopia, with resistance to grain mold and anthracnose.

Partnerships made: Ethiopian Agricultural Research Institute (EIAR) and Bako Agricultural Research Center (Oromia Agricultural Research Institute (OARI)

Next steps: Materials identified are being tested in a preliminary yield trial scheme across locations to select the best performing lines for disease and other traits.

Target countries: Ethiopia

10. Technology: Pre-release of two new high yielding multipurpose Melanaphis resistant varieties for Haiti (new)

Category: Biological

Area of inquiry: Genetic enhancement

Description: Two new varieties are being pre-released by Chibas for participatory evaluation with selected growers before complete release (expected at the end of 2019). These 2 inbreds have been part of the extensive phenotyping and genotyping of all of Chibas's inbreds carried with support of the USAID-SMIL project. Both showed the highest breeding value with genomic prediction and broad adaptation under the 11 environments in which the varieties have been evaluated under the USAID-SMIL grant/project.

Partnerships made: Université Laval

Next steps: These varieties are now moving to production of "breeders' seed" so that in the 2 seasons of 2019 (spring and autumn) they can be evaluated by participating farmers (participatory evaluation) before complete release (expected late 2019 or early 2020). Registration process is being initiated with the National Seed System (SNS) of the Ministry of Agriculture for these 2 varieties.

Target countries: Haiti

Phase 3 technologies – Made available for transfer

1. Technology: Seed balls to reduce risk and improve yield in Sahelian pearl millet based farming systems

Category: Management practices

Area of inquiry: Genetic enhancement

Description: Seed balls are a sowing technique for semi-arid areas, especially aiming at the improvement of plant establishment with dry sowing. Seed balls represent a mixture of soil material, seeds and additives (e.g. nutrients, pesticides). They aim at small-grain cereal cropping system with wide spacing (seed pockets).

Partnerships made: Fuma Gaskiya - Maradi, Niger (farmer organization); FAPAL - Louga, Senegal (farmer organization); INRAN – Niamey, Niger

Next steps: Field testing in 2017 has shown that the technology works using materials from different locations. Now the technology needs to be described in detail and distributed to other Sahelian areas, where applicable.

Target countries: Senegal and Niger

2. Technology: Mass rearing of parasitoids for biological control

Category: Management practices

Area of inquiry: Production systems management

Description: Results indicated that adding 50% cowpea floor to the millet diet enhance mass production of parasitoids. With a starting number of 25 C. cephalonica larvae kept for a three-month rearing period, the improved diet will produce 2.68 million larvae and 10 million H. hebetor adult parasitoids.

Partnerships made: None at this time

Next steps: The new formula will be shared with the farmer cooperatives for uses in the parasitoid production

Target countries: Senegal and Niger

3. *Technology: Direct release of Habrobracon hebetor adults for controlling the millet head miner*

Category: Management practices

Area of inquiry: Production systems management

Description: It was determined that the release of 800 parasitoids per 3km radius in the early panicle stage of the crop give a good level of control of the head miner. The 800 parasitoids correspond to 12 parasitoid bags, this will reduce the current numbers by (20%) for 3km radius. Given the current price of $3.34/bag, a saving of $10 is expected per each release. Progress was made in the identification of numbers of H. hebtor adults needed per acreage of pearl millet for controlling the millet head miner.

Partnerships made: The technology has been transferred to farmer cooperatives in Niger

Next steps: Discuss with donors and USAID value chain projects to support the dissemination

Target countries: Senegal and Niger

4. *Technology: Hybrids for commercial sorghum seed industry*

Category: Biological

Area of inquiry: Genetic enhancement

Description: White sorghum hybrids P9511A/PRL020817 (K9058) registered and released with 5.76 t/ha yield performance for use in lowland growing areas of Ethiopia.

Partnerships made: Collaboration with the Ethiopian Seed Enterprise (ESE) and Regional Seed Enterprise (RSE) have been developed.

Target country: Ethiopia

5. *Technology: Registered germplasm with sugarcane aphid resistance for global use (new)*

Category: Biological

Area of inquiry: Genetic enhancement

Description: Registration of RTx3410 through RTx3428 sorghum germplasm resistant to sugar cane aphid.

Partnerships made: Partnerships have been established with several US based seed companies who will introduce this germplasm in their breeding programs.

Target countries: Global

Environmental Management and Mitigation Plan (EMMP)

The Sorghum and Millet Innovation Lab management entity has continued to support environmental compliance and ensure that the resources, responsibilities and reporting (3R's) have been well defined and monitored throughout the lifetime of each research project implementation. The Lab management entity also continues to ensure that the research activities being funded comply with the environmental compliance requirements as stated in the initial environmental evaluation.

The Lab management entity has worked with the respective implementing partners and their existing environmental compliance staff and structures to strengthen and align environmental compliance measures. The associated environmental monitoring and mitigation plans (EMMPs) for each research project have been supported by an EMMP web based module, which facilitates reporting of actual environmental support visits by the environmental compliance staff and investigators of the implementing partner, as well as other relevant persons involved.

Figure 2: Environmental compliance poster presented at SMIL annual meeting

Open data management plan

The Sorghum and Millet Lab continues to maintain an open data management plan on file with USAID. Through the Lab's Resource and Reporting Hub, the management entity monitors the status of existing data sets produced under Lab funding, including the location for public access to that data. Because the FY 2018 was the first year where most data sets were beginning to become available for public publication, the Lab is in the process of developing its management processes. However, during FY 2018, fourteen different entries were made by project investigators of data set submission, with this data being uploaded to multiple types of repositories including the Texas Data Repository, Dataverse, Dryad and the USAID Development Data Library. The management entity continues to develop its open data management plan in full as it supports its projects in executing compliance around USAID policy.

Governance and management entity activity

In FY 2018, the management entity focused on building global and regional networks around sorghum and millet. Additionally, the Lab also took specific steps to prepare for the overall application of technologies developed during the program's first five years.

Global Sorghum Conference

In a capstone component of the program's first five years, the Sorghum and Millet Innovation Lab spearheaded the organization and execution of *Sorghum in the 21st Century: Food, Feed and Fuel in a Rapidly Changing World*, a global sorghum conference that took place on April 9-12, 2018 at the Century City Convention Center in Cape Town, South Africa. As the first global conference on sorghum in over 25 years, the event saw the attendance of more than 400 international researchers, industry professionals, government representatives and development specialists around a broad variety of sorghum-related topics, including food security, value-added products, genetics, global trade, climate-smart agriculture and more. A total of 567 abstracts were received, 197 posters presented, 132 presentations provided and a strong technical exhibition organized over the four-day conference. In addition to the plenary sessions, the conference had five thematic tracks, as well as three symposia and two special sessions. The conference delegates represented 40 different countries from around the world (Figure 3). A large database of some 2,000 contacts was developed and regular conference updates were disseminated by e-mail across the global sorghum research and development community.

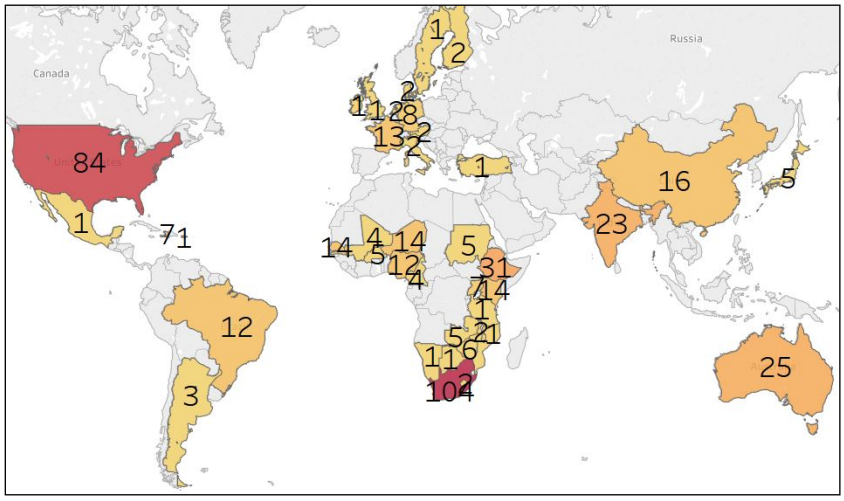


Figure 3. Global sorghum conference participants by country of origin

The conference was co-hosted by the University of Pretoria and offered a unique opportunity to convene around crucial issues for the global sorghum community. It was sponsored by numerous international and local organizations and institutions including the United States Agency for International Development (USAID), the United States Department of Agriculture (USDA), the Australian Sorghum Conference Committee, the United Sorghum Checkoff Program, the McKnight Foundation, the South African Department of Science and Technology and National Research Foundation, and corporations among others. The aim was to bring the global community together to establish priorities and collaboration that will lead to key developments in sorghum in the years to come. As a result of this conference, long-term multi-disciplinary cooperation was strengthened. Participants returned to their home countries with key multi-discipline contacts to strengthen their research and development work. More information about the Sorghum in the 21st Century conference can be found at: https://21centurysorghum.com/.

Approximately 400 participants from 40 different countries were in attendance at the 2018 Sorghum in the 21st Century global sorghum conference.

2018 West Africa Regional Pearl Millet Convening

Nearly 90 researchers and stakeholders from across the West Africa pearl millet value chain came together at a regional convening co-hosted by the Sorghum and Millet Innovation Lab on September 4-6, 2018 in Thies, Senegal. Targeted at major actors in pearl millet from Senegal, Niger, Mali and Burkina Faso, the *2018 West Africa Regional Pearl Millet Convening* was also co-hosted by the Centre d'Etude Régional pour l'Amélioration de l'Adaptation à la Sécheresse (CERAAS), and the USDA sponsored NCBA CLUSA Millet Business Services Project.

The objective of the convening was to provide a forum for the exchange of needs and opportunities by pearl millet stakeholders (including input suppliers, farmers, processors, etc.) with agricultural researchers focused on technological innovation. Over three days, the participants presented current pearl millet value chain activities in several West African countries and discussed technological bottlenecks to improved productivity and profitability of their activities. The groups broke out across subareas and worked together to prioritize the most pressing issues in the West African pearl millet industry. The findings from those breakout groups were made available publicly and will be used to drive future research in the area. Additional information can be found at: http://www.k-state.edu/smil/whatwedo/pearl_millet/index.html.

Technology scaling

Scaling technology packages is a key program deliverable for the Sorghum and Millet Innovation Lab. In order to prepare for related activities, a scaling assessment was undertaken for each technology package at a Phase III level that are ready for scaling. The PPP Lab scaling scan tool (https://ppplab.org/wp/wp-content/uploads/2017/11/PPPLab-Scaling-Final-17-10.pdf) was used in collaboration with Lab partners to better assess the potential for scaling and areas of strengthen and weakness. This tool addresses ten scaling "ingredients " including technology practice, awareness/demand, business case, value chain integration, finance, knowledge/skills, collaboration networks, evidence/learning level, leadership/management, and public sector governance. Summary bar and spider graphs can be generated which provide a helpful graphic to access strength and weak ingredients and consider means to address them in a scaling plan. This assessment will be considered as scaling plans are solidified moving into the program's second phase of research activities.

Gender study: Sorghum production and utilization in Ethiopia

During its first five-year phase, the Sorghum and Millet Innovation Lab commissioned a gender study led by gender consultant Yeshi Chiche in Ethiopia. The purpose of the study was to assess gender roles and sorghum production/utilization by region in Ethiopia. In 2017, Ms. Chiche and the regional research teams implemented village-level data collection in six different regions using focus group interviews and rapid rural appraisals. The data from those interviews was aggregated into individual regional reports and presented at a project debrief meeting in August 2017. The data was later presented at the *Sorghum in the 21st Century* global sorghum conference in April 2018 and the reports were professionally edited in the fall of 2018 for further distribution and publication.

Other Topics

The Lab management entity continues to be engaged at a university level to contribute to the overall processes and systems at Kansas State University (and other partner institutions) with the objective of creating more effective, efficient and streamlined systems. Regular communication and meetings around relevant topics or challenges occurred throughout FY 2018 and the resulting institutional relationships only continue to be strengthened.

Also during this period, USAID commissioned an external evaluation of the Sorghum and Millet Innovation Lab's first five years. This process involved the compilation of a comprehensive set of documentation to provide in-depth understanding of the Lab's activities and achievements, as well as both Zoom and on-site visits by the evaluation team to Kansas State University to meet with the management entity as well as project principal investigators. The evaluation team later visited in-country project sites to speak in-person with national partners and observe program activities.

With the close of FY 2018 and the successful extension of the Lab through 2023, the management entity shifted into planning mode for the next five years. This will include review of project performance and proposals for a second phase of activities, strategic competitive calls for proposals around pearl millet and sorghum pathology, and the identification of any additional missing areas in the program's portfolio of research. This process will continue in earnest through the first quarter of FY 2019, with contracting and implementation to be in in the second quarter of FY 2019.

Future directions

The Sorghum and Millet Innovation Lab was awarded an extension until July 19, 2023. During the second five-year phase, the program will promote research and development activities that will be impactful to end-users whether that be producers, consumers, processors or the next generation of scientists.

The management entity philosophy is one of adaptation to emerging challenges and opportunities combined with a result-based analysis of each project's contribution to national and regional agricultural objectives. The project reports provide one piece of information into the results-based analysis in relation to priorities. Open and competitive calls for research and development activities will be held in targeted areas of need, for example in the pearl millet value chain and plant pathology.

In addition to the evaluation and development of a research project profile, the management entity will continue to facilitate technology transfer in a strategic way. The management entity has been proactive in linking projects with the next users of information and technologies, in developing networks and awareness of programmatic activities and in the marketing of innovations. The program will build upon long-term training achievements by empowering those graduates to be productive as they return to their host institutions.

Appendices

Appendix 1 – Success stories

WHITE SORGHUM HYBRID RELEASED IN ETHIOPIA TO BRING INDUSTRY ONE STEP CLOSER TO A COMMERCIAL SORGHUM SEED SYSTEM

Ethiopia has long been recognized as the center of genetic origin for sorghum. The East African country has immense genetic diversity across its countless sorghum land races, and the crop plays a key role for farmers, entrepreneurs and consumers alike. Yet, despite its important place in the economy and culture, one area of challenge remains for the sorghum industry – the lack of a commercial sorghum seed system. A sustainable and effective commercial seed system can offer greater consistency and reliability to producers which can, in turn, result in better performing, higher quality sorghum crops that can be marketed at higher value.

In an effort to address this need while simultaneously developing better varieties with improved adaption to local production environments, researchers at Purdue University teamed up with the Ethiopian Institute for Agricultural Research (EIAR) in partnership with regional centers and universities to release and register a white sorghum hybrid variety in Ethiopia. The project was led by Dr. Gebisa Ejeta of Purdue and supported by the Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet.

As part of these activities, the team introduced and tested available experimental sorghum hybrids under local conditions in Ethiopia. The hybrids showed excellent performance in terms of field performance and yield and the one particular variety was strongly preferred both by farmers and researchers at their respective sites during field evaluation

The hybrid, K9058, is an early-maturing and high-yielding hybrid demonstrating strong drought tolerance. It also demonstrates good qualities for *injera* production (*injera* is a staple bread product consumed throughout Ethiopia), making it a desirable variety for both producers and consumers.

The release of this hybrid within Ethiopia is a key step in the establishment of a strong hybrid sorghum breeding program that can then serve as a catalyst for the development of a commercial sorghum seed system. Seed multiplication is now under way at the regional seed enterprises with plans for demonstration and uptake by smallholder farmers and large poultry producers.

A researcher observes field performance of the K9058 white sorghum hybrid in Ethiopia.

DISEASE-RESISTANCE GENE LOCATED IN SORGHUM IN BREAKTHROUGH DISCOVERY

Anthracnose is a widespread disease caused by a fungus that can have devastating effects on sorghum production. It occurs in numerous locations around the world, and is especially prevalent in areas of high humidity, many regions in Africa and the southern United States. One research team, however, may have just unlocked a powerful key in the fight against the disease's destruction.

"Anthracnose is one of the most important and widespread diseases in sorghum-growing areas," says Dr. Tesfaye Mengiste, an Ethiopian-born professor of plant pathology at Purdue University. "If a plant is exposed and does not have a gene for anthracnose resistance, it will die."

When the fungus that causes anthracnose attacks a plant, it multiplies in the leaves, feeding on the plant's nutrients until the plant can no longer photosynthesize. Inevitably, the entire plant will die. The end result is lost yields, lost income and lost food security.

Mengiste leads a team of researchers from Purdue University, the Ethiopian Institute for Agricultural Research, Oromia Agricultural Research Institute, and Holleta Biotechnology Center in a project aimed to enhance sorghum productivity and improve the livelihood of sorghum farmers in western Ethiopia through a collaborative research program focused on developing new, innovative interventions in crop disease resistance. The project is funded by the Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet.

Anthracnose is a common problem across Ethiopia, but is particularly brutal in the western half of the country, where it is significant and severe and can devastate fields and families. While larger scale farmers in countries such as the U.S. have more ready access to fungicides to control fungal diseases, smallholder farmers in Ethiopia and other regions often experience much more limited access to inputs and treatment options, leaving them especially vulnerable to anthracnose and other diseases.

Mengiste's team has been looking for ways to fight anthracnose genetically in order to be able to introduce resistance to the disease directly into susceptible varieties, which would allow it to flourish even in the presence of the fungus without the need for fungicide treatments.

"Genetic resistance is the most sustainable and inexpensive way to control this disease," says Mengiste.

After years of research, Mengiste may have found just that. Recent results have shown that his team have successfully identified two key genes that carry anthracnose resistance in sorghum. These genes show the promise of integrating widespread anthracnose resistance into existing sorghum varieties in Ethiopia, and preventing countless food and income losses by smallholder farmers.

The next steps in the research, Mengiste says, will be to begin crossing the existing sorghum germplasms that carry the resistance genes into farmers' favorite varieties. Researchers will then select the materials that combine both the anthracnose resistance and other desirable traits to have overall better performing varieties at the disposal of Ethiopia's sorghum producers.

However, Mengiste's research will not stop at Ethiopia's borders. This important discovery will be applied to sorghum verities planted around the world – including in the U.S. - to result in better crops to benefit all.

Anthracnose-resistant lines tower over susceptible ones at a research station in Jimma, Ethiopia.

K-STATE INNOVATION LAB CO-HOSTS REGIONAL MILLET CONVENING IN WEST AFRICA

Nearly 90 researchers and stakeholders from across the West Africa pearl millet value chain came together at a regional convening on September 4-6, 2018 in Thies, Senegal. Targeted at major actors in pearl millet from Senegal, Niger, Mali and Burkina Faso, the event was co-hosted by the Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet, the Centre d'Etude Régional pour l'Amélioration de l'Adaptation à la Sécheresse, and the U.S. Department of Agriculture's NCBA CLUSA's Millet Business Services Project.

The objective of the convening was to provide a forum for the exchange of needs and opportunities by pearl millet stakeholders — including input suppliers, farmers, processors, consumers, etc. — with agricultural researchers focused on technological innovation. Over three days, the participants presented current pearl millet value chain activities in several West African nations and discussed technological bottlenecks to improved productivity and profitability of their activities. The groups broke out across subareas and worked together to prioritize the most pressing issues in the West African pearl millet industry. The findings from those breakout groups were made available publicly and will be used to drive future research in the area.

Pearl millet is a staple crop across West Africa, particularly in the semi-arid areas of the Sahel. Its hardiness and drought tolerance make it particularly adapted to the challenging Sahelian climate, and its nutritive content and versatility make it a key foundation to diets for humans and animals alike. Growth in urban populations and average household incomes across the region has also led to an increasing demand for millet-based food products that are both nutritious and easy to prepare, offering new opportunities for entrepreneurs and businesses. The Sorghum and Millet Innovation Lab and other partnerships hope to harness these opportunities to contribute to the establishment of new initiatives aimed at improving both food and income security in the region.

The Feed the Future Innovation Lab for Collaborative Research in Sorghum and Millet is a consortium of cutting-edge research aimed at improving the adaptation and resilience of sorghum and pearl millet to the semi-arid climates of East and West Africa. It was established in July 2013 at Kansas State University to contribute technologies and knowledge toward the adaptation, resilience, and improved profitability of sorghum- and millet-based production systems and value chains through a grant from USAID as part of Feed the Future, the U.S. Government's global hunger and food security initiative. The lab links U.S. and international universities and research organizations in a collaborative effort to build human and institutional capacity in Ethiopia, Niger, Senegal, Burkina Faso, Mali and Haiti to make sorghum and pearl millet the crops of the future. Additional information regarding the Lab can be found at k-state.edu/smil.

Nearly 90 researchers and stakeholders from across West Africa were in attendance to tackle important issues at the 2018 West Africa Regional Pearl Millet Convening.

Appendix 2 – List of awards to U.S. partners

Title: Combining high digestible protein trait with waxy/ heterowaxy endosperm traits to develop superior functionality in sorghum for food applications to promote sorghum value chain in Ethiopia
Award: Texas A&M - Joseph Awika
Project Dates: 04/01/14 07/22/18

FY18 Funding Released:	$142,468.00
Total Funding Released:	$809,941.00
Overall Project Budget:	$809,941.00

Title: Biological Control of the Millet Stem Borer and the Millet Head Miner in Niger and Senegal
Award: Virginia Tech - Malick Ba
Project Dates: 04/01/14 07/22/18

FY18 Funding Released:	$2,520.00
Total Funding Released:	$207,017.00
Overall Project Budget:	$207,017.00

Title: Genetic Enhancement of Sorghum to Promote Commercial Seed Supply and Grain Market Development in Ethiopia
Award: Purdue - Gebisa Ejeta
Project Dates: 04/01/14 07/22/18

FY18 Funding Released:	$133,562.00
Total Funding Released:	$713,203.00
Overall Project Budget:	$713,203.00

Title: Expanding Markets for Sorghum and Millet Farmers in West Africa through Strengthening of Entrepreneur Processors and Nutrition-based Promotion of Products
Award: Purdue - Bruce Hamaker
Project Dates: 04/01/14 07/22/18

FY18 Funding Released:	$57,378.00
Total Funding Released:	$598,938.00
Overall Project Budget:	$598,938.00

Title: Genetic improvement of sorghum for resistance to fungal pathogens
Award: Purdue - Tesfaye Mengiste
Project Dates: 04/01/14 07/22/18

	Purdue	KSU	Total
FY18 Funding Released:	$122,903.00	$24,865.00	$147,768.00
Total Funding Released:	$731,293.00	$188,924.00	$920,217.00
Overall Project Budget:	$731,293.00	$188,924.00	$920,217.00

Title: Development of Biotic Stress-Resistant Sorghum cultivars for Niger and Senegal
Award: WTAMU - Bonnie Pendleton
Project Dates: 04/01/14 07/22/18

FY18 Funding Released:	$71,320.00
Total Funding Released:	$639,937.00
Overall Project Budget:	$639,937.00

Title: Improved Crop Genetics and Processing Methods for Increased Productivity and Nutrition for the Smallholder Sorghum Producers in Ethiopia
Award: KSU - Tesfaye Tesso
Project Dates: 04/01/14 07/22/18

	KSU	USDA	Total
FY18 Funding Released:	$106,674.00	$0.00	$106,674.00
Total Funding Released:	$370,722.00	$147,441.00	$518,163.00
Overall Project Budget:	$370,722.00	$147,441.00	$518,163.00

Title: Sorghum Trait Development Pipeline for Improved Food and Feed Value
Award: Purdue - Mitch Tuinstra
Project Dates: 04/01/14 07/22/18

FY18 Funding Released:	$0.00
Total Funding Released:	$847,667.00
Overall Project Budget:	$847,667.00

Title: Improving sorghum adaptation in West Africa with genomics-enabled breeding
Award: KSU - Geoff Morris
Project Dates: 04/01/14 07/22/18

FY18 Funding Released:	$131,812.00
Total Funding Released:	$564,035.00
Overall Project Budget:	$564,035.00

Title: Pearl Millet Improvement for Productivity, Climate Resilience and Nutritional Quality
Award: KSU-Hays - Desalegn Serba
Project Dates: 07/01/16 07/22/18

FY18 Funding Released:	$6,300.00
Total Funding Released:	$23,348.00
Overall Project Budget:	$23,348.00

Title: Implement a genomics-assisted breeding program in a small breeding program in a developing country
Award: Cornell - Ed Buckler
Project Dates: 10/01/16 09/30/19

FY18 Funding Released:	$170,763.00
Total Funding Released:	$410,796.00
Overall Project Budget:	$582,127.00

Title: Pearl Millet Improvement for Productivity, Climate Resilience and Nutritional Quality
Award: KSU - Geoff Morris
Project Dates: 10/01/16 09/30/19

FY18 Funding Released:	$0.00
Total Funding Released:	$206,640.00
Overall Project Budget:	$206,640.00

Appendix 3 – Country-specific financial information

		Country Total								
Project Title	**Principle Investigator**	**Burkina Faso**	**Ethiopia**	**Ghana**	**Mali**	**Niger**	**Senegal**	**South Africa**	**Germany**	**Haiti**
Country Coordination (Ethiopia, Niger, Senegal)		-	82,465	-	-	209,844	55,200	-	-	-
Improving sorghum adaptation in West Africa with genomics-enabled breeding	Geoff Morris	-	-	-	37,197	213,283	328,321	-	-	-
Combining high digestible protein trait with waxy/ heterowaxy endosperm traits to develop superior functionality in sorghum for food applications to promote sorghum value chain in Ethiopia	Joseph Awika	-	182,718	-	-	-	-	90,000	-	-
Biological control of the millet head miner in Niger and Senegal	Malick Ba	-	-	-	-	311,596	120,175	-	-	-
Development of biotic stress-resistant sorghum cultivars for Niger and Senegal	Bonnie Pendleton	-	-	-	-	88,826	90,000	-	-	-
Expanding markets for sorghum and millet farmers in West Africa through strengthening of entrepreneur processors and nutrition-based promotion of products	Bruce Hamaker	-	-	-	-	134,440	109,000	-	-	-
Genetic improvement of sorghum for resistance to fungal pathogens	Tesfaye Mengiste	-	168,700	-	-	-	-	-	-	-
Optimization of the seed ball technology for pearl millet, and agronomic and socio-economic evaluation in the context of smallholder farmers in Senegal and Niger	Ludger Herrmann	-	-	-	-	73,834	55,770	-	61,936	-
Genetic Enhancement of sorghum and millets to promote commercial seed supply and grain market development in Senegal and Ethiopia	Gebisa Ejeta	-	199,500	-	-	-	-	-	-	-
Improving crop genetics and processing methods for increased productivity and nutrition for smallholder sorghum producers in Ethiopia	Tesfaye Tesso	-	220,259	-	-	-	-	-	-	-
Sorghum trait development pipeline for improved food and feed value	Mitch Tuinsta	-	-	210,000	-	149,500	149,500	-	-	-
Development of dual-purpose pearl millet varieties for the benefit of farmers and agro-pastoralists in the Sahelian and Sudanian zones of West Africa	Roger Zangre	126,321	-	-	113,146	113,121	113,121	-	-	-
Molecular diversity study of pearl millet parental lines	Desalegn Serba	-	-	-	-	3,336	3,220	-	-	-
Implement a genomics-assisted breeding program in a small breeding program in a developing country	Ed Buckler	-	-	-	-	-	-	-	-	204,240
	Total	**126,321**	**853,642**	**210,000**	**150,343**	**1,297,780**	**1,024,307**	**90,000**	**61,936**	**204,240**