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 2019

October 1, 2018 – September 30, 2019

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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 2019

This annual performance report for FY 2019 is made possible by the generous support of the American people through the United States Agency of International Development (USAID). The contents are the responsibility of Kansas State University and do not necessarily reflect the views of USAID or the United States Government.

Program activities are funded by the United States Agency for International Development (USAID) under Cooperative Agreement No. AID-OAA-A-13-00047.

Cover photo:
Women producing millet seedballs during a workshop near Maradi, Niger
Photo credit: Ludger Herrmann

This publication may be cited as:
Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet. October 2019. Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet Annual Performance Report FY 2019. Sorghum and Millet Innovation Lab, Kansas State University, Manhattan, KS, 74 pp.

Management entity information

As in previous years, the core management entity team did not see any changes in staffing during FY 2019, thus maintaining the same program staff members as follows:

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

With the launch of Phase 2 projects, the management entity's in-country coordination team has seen some changes as follows:

- Senegal – Dr. Ndjido Kane of the Centre d'Etudes Régional pour l'Amélioration de l'Adaptation à la Sécheresse (CERAAS)
- Niger – Dr. Moustapha Moussa of the Institut National de la Recherche Agronomique du Niger (INRAN)
- Ethiopia – Dr. Habte Nida (Ejeta project), Dr. Getachew Ayana (Mengiste project) and Dr. Alemu Tirfessa (Awika project) of the Ethiopian Institute of Agricultural Research (EIAR) (Individual project coordinators/co-PIs are assigned on a per project basis, according to EIAR policy)

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 currently serves as a co-PI on the new Phase 2 project, "Genetic Enhancement of Pearl Millet for Yield, Biotic and Abiotic Stress Tolerance in West Africa (GENMIL)," led by Dr. Ndjido Kane of CERAAS, and will be serving as advisor to a Senegalese student scheduled to begin her Ph.D. training in agronomy on the genetic enhancement of pearl millet in the spring of 2020.

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. All original five members elected to continue their service into Phase 2, 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 December 2018, the EAB came together in Washington, D.C. for a three-day meeting with the management entity to for Phase 2 program planning and project selection. The board evaluated all projects that were under consideration for Phase 2, and also discussed potential approaches to a new West Africa sorghum pathology project and proposed economics research. The management entity left the meeting with key input and a clear plan on the next steps that were needed to fully implement the Lab's second phase of research activities.

Also, 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.

Focus countries

The Lab continues to work primarily in its focus countries – Ethiopia, Senegal and Niger – and secondarily in Burkina Faso, Mali and Haiti, with an addition of Togo in this phase. Activities in Haiti are supported through an associate award initiated in FY 2016 that received a no-cost extension through 2021.

Figure 1: Sorghum and Millet Innovation Lab map of program activities and partners

List of program partners

United States

Cornell University
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
West Texas A&M University

Ethiopia

Amhara Agricultural Research Institute
Amhara Bureau of Agriculture and Natural Resources
Ethiopian Institute of Agricultural Research (EIAR)
Haramaya University
Hawassa University
Holleta Biotechnology Center
Oromia Agricultural Research Institute
Tigray Agricultural Research Institute

Senegal

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

Niger

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

Mali

Institut d'Economie Rurale (IER)

Burkina Faso

Institut de l'Environnement et de Recherches Agricoles (INERA)

Togo

Institut Togolais de Recherche Agronomique (ITRA)

Haiti

CHIBAS
Quisqueya University

Germany

University of Hohenheim

France

Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)

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 Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet completed its sixth year during the fiscal year, and this concluded all project activities that were granted a no-cost extension from the first phase (2013-2018). At the same time, new projects for the second phase of the program (2018-2023) initiated activities, and follow-on projects from the first phase transitioned to a new set of objectives and activities. Two new projects were initiated in West Africa after a competitive call for proposals--one on pearl millet breeding and another on sorghum pathology--while projects on dual-purpose pearl millet varieties, integrated pest management, sorghum entomology and sorghum breeding in Ethiopia concluded.

In the second phase of the program, projects were encouraged to focus on the continued development and refinement of products for downstream application for producers, processors and consumers by harvesting advancements in knowledge, technologies and delivery science generated during the first phase. At the same time, projects will continue to develop global public goods for the scientific community.

This annual report focuses on this transitional year and contains final reporting from the first phase and first year reporting on projects selected for the second phase. The second phase projects continued from the first phase will be linked to activities described in prior reports while the two new projects will describe start-up activities.

Program activities and highlights

The first year of the second phase of the Sorghum and Millet Innovation Lab was completed during FY 2019. For several projects, this year served as a continuation of activities conducted in the first phase (2013-2018) and a transition into downstream activities aimed at delivering new products into the innovation system. The end of the first phase also brought the closure to three projects while the start of the second phase saw the development of two new projects.

The program continues to focus the largest share of its research funding in the area of genetic enhancement of sorghum and pearl millet. In Ethiopia, two projects focus the entirety of their activities on sorghum germplasm improvement and a third project focuses partially in this area while linking the breeding work to the development of value-added food products. In West Africa, four projects focus on germplasm improvement: three on sorghum and one on pearl millet including a new project focusing on increasing sorghum host plant resistance against pathogens and a project on pearl millet genetic improvement. The breeding programs in West Africa do not stand alone but play a role in a broader consortium of research supported by numerous donors in order to maximize the impact of our investment in the broader research "ecosystem."

The program continues to support agronomic and economic research of pearl millet seedballs in Niger. During the first phase, this project demonstrated significant advances in understanding some of the agronomic factors affecting the seedballs and conducted large-scale on-farm tests in collaboration with the Nigerien farmers' cooperative *FUMA GASKIYA*. The collaborative activities between research and development have helped to refine areas of improvement with the technology through gender-differentiated trials and experimentation.

The program continues to support research on using sorghum and pearl millet in value-added food products in Ethiopia, Senegal and Niger. In Ethiopia, coordinated research between food scientists, industry and sorghum breeders continue to identify new opportunities for high protein and highly digestible hybrid varieties in staple products such as *injera* and baked goods. In West Africa, research is focusing on elevating the capacity of the Senegalese institute for food science to conduct world-class sensory evaluation of food products and new grain varieties while "fine-tuning" new food products to meet consumer needs. In Niger, the program continues to develop and evaluate the potential of new agglomerated food products and composite flours for consumer acceptance.

The management entity continues to pursue opportunities to scale new technologies with downstream development organizations including the United Nations, national development programs funded by USAID and private sector firms engaged in product development, seed multiplication and input supply. The management entity continues to collaborate with U.S. agricultural stakeholders to bring the benefits of international research to bear upon U.S. sorghum and pearl millet productivity.

Key accomplishments

A competitive call for proposals was issued to develop new projects in pearl millet breeding and sorghum pathology and over 25 proposals were received. A NSF-style review and project selection process was conducted and two new projects were selected. These projects were contracted and initiated in FY 2019.

Additionally, the Lab supported a total of 21 long-terms trainees during the fiscal year. The group also represents a variety of degree levels with two Bachelor's, two Master's, 17 Ph.Ds. Seventeen males were trained and four females.

In FY 2019, the Lab trained a total of 386 individuals in 14 trainings. Producers made up the largest group.

New technology packages have evolved, making some ready for the scaling process to farmers and others for the research community. These include:

- Pre-release of two new high-yielding sugarcane aphid resistant varieties in Haiti.
- Prototypes of a mechanized seedball fabrication tool were developed.
- Highly digestible sorghum varieties were transferred to ISRA for introgression with local varieties.
- Anthracnose resistant genes were discovered in Ethiopian germplasm.
- Improved highly digestible and high protein hybrids entered into the national release system in Ethiopia.
- New tools for genomics-enabled breeding developed for the West African sorghum improvement community.
- Composite flour mixes utilizing locally available micronutrient fortificants developed for West Africa.
- Georeferenced database of key sorghum pathogens developed for West Africa.

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 nine projects and funding commitments to 15 institutions. Projects are led by several institutions including Purdue University (four projects), Kansas State University (one project), Texas A&M (two projects), the Senegalese Institute for Agricultural Research (ISRA – one project) and the University of Hohenheim (one project). The pearl millet improvement project is being led by the Senegalese national agriculture research program (ISRA) and integrates researchers from Burkina Faso, 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. There are activities in Haiti under an Associate Award that are led by Cornell University.

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, sixty-seven percent of our projects focus on sorghum and pearl millet crop improvement, eight percent in production systems management and twenty-four percent in added-value products. Geographically, slightly more than 35% of Lab financial resources for research are focused on Ethiopia and the remainder in West Africa.

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:

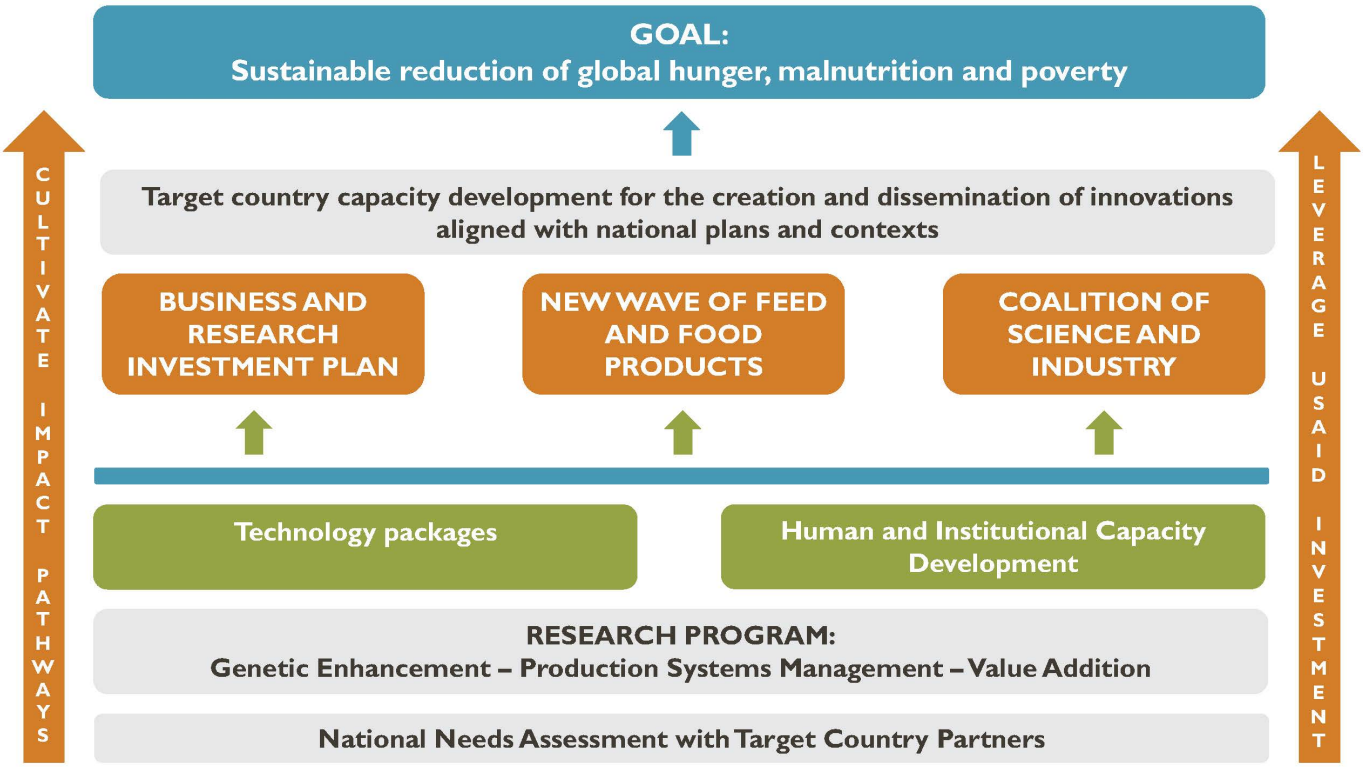

Figure 2: Sorghum and Millet Innovation Lab Theory of Change

The theory of change embedded in the Sorghum and Millet Innovation Lab's activities is based upon a "bottom 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 has been developed that features technology packages at the Phase III level. Using a scaling tool, a scaling scan per technology package is completed to better assess the potential for scaling. This includes 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 is leveraging 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 is building 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

The Sorghum and Millet Innovation Lab's first phase of research activities came to a close following a year-long no-cost extension that ended on July 22, 2019. All projects were evaluated by the Lab management entity, and some were given the opportunity to submit a proposal for an additional continuation of research activities into Phase 2. Those Phase 2 continuation projects had a contractual start date of April 1, 2019. In addition, two new projects were developed and contracted during FY 2019 as a part of the Phase 2 portfolio.

PHASE I PROJECTS (FINAL REPORT – NO PHASE 2 CONTINUATION)

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 - USA

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, *Build a coalition of science and industry around sorghum and millet*. 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

All project activities were completed in the previous fiscal year (2018).

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

All project activities were completed in the previous fiscal year (2018).

Presentations and publications

All project activities were completed in the previous fiscal year (2018).

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

Led by
Dr. Bonnie Pendleton
West Texas A&M University - USA

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, *Build a coalition of science and industry around sorghum and millet*. 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
Strategies to reduce post-harvest loss from insect damage were developed and extended to farmers. In-field assessment of insect pests on sorghum revealed a correlation between insect damage and disease incidence.

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 project evaluated numerous strategies to reduce insect damage during the crop production phase and at the post-harvest storage levels. Both phases require evaluation of the economic threshold for pesticide application and also determined whether prophylactics are a cost-effective strategy to prevent insect damage. In addition, sorghum lines were screened in Senegal for resistance against the sorghum midge.

Presentations and publications

Hamé, A. Assessing Management Strategies to Control Major Insect Pests of Stored Sorghum Grain.

Hamé, A. & Pendleton, B. B. (November 2018). Evaluating botanicals to control maize weevil (Coleoptera: Curculionidae) in stored sorghum grain. 2018 Texas A&M University System 15th Annual Pathways Student Research. West Texas A&M University, 1-2 November 2018, Canyon, Texas, USA.

Hamé, A. & Pendleton, B. B. (November 2018). Evaluating botanicals to control maize weevil, Sitophilus Zeamais, in stored sorghum grain. 2018 Joint Annual Meeting of the Entomological Society of America (ESA), Entomological Society of Canada (ESC) and Entomological Society of British Columbia (ESBC): "Crossing Borders: Entomology in a Changing World". 11-14 November 2018, Vancouver, BC, Canada

Hamé, A. & Pendleton, B. B. (November 2018). Evaluating botanicals to control maize weevil, Sitophilus Zeamais, in stored sorghum grain. 2018 Joint Annual Meeting of the Entomological Society of America (ESA), Entomological Society of Canada (ESC) and Entomological Society of British Columbia (ESBC): "Crossing Borders: Entomology in a Changing World". 11-14 November 2018, Vancouver, BC, Canada

Hamé, A. & Pendleton, B. B. (March 2019). Evaluating local botanicals for control of Red Flour Beetle, Tribolium castaneum Herbst, in stored sorghum grain. 14th Annual Faculty Research Poster Session and Research Fair, Canyon, Texas USA

Hamé, A. & Pendleton, B. B. (April 2019). Evaluating botanical powders to control maize weevil, Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae), in stored sorghum grain. 67th Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists., Tulsa, Oklahoma

Hamé, A., Almas, L., & Pendleton, B. B. (July 2019). Food security aspects in Niger: Challenges and opportunities. 12th Annual International Symposium on Agricultural Research, Athens, Greece

Hamé, A., Pendleton, B. B., & Almas, L. (March 2019). Food security aspects in Niger: Opportunities and Challenges. 14th Annual Faculty Research Poster Session and Research Fair, Canyon, TX USA

Pendleton, B. B. & Hamé, A. (March 2019). Assessing diversity of and alternative management strategies for insect pests of stored sorghum. 13th Annual Faculty Research Poster Session and Research Fair, Canyon, Texas, USA

Triplett, E. L. & Pendleton, B. B. (April 2019). Analyzing the significance of photoperiod on fitness of sugarcane aphid, Melanaphis sacchari, on sorghum. 67th Annual Meeting of the Southwestern Branch of the Entomological Society of America and Annual Meeting of the Society of Southwestern Entomologists, Tulsa, Oklahoma, USA

Thiam, A. N., Sarr, I., NDiaye, S., Kandji, O., Pendleton, B., Peterson, G., & Cissé, N. (October 2018). Occurrence of the sorghum midge (Stenodiplosis sorghicola, Diptera: Cecidomyiidae), development cycle and resistance of different sorghum lines in Senegal (pp.442-448). Journal of Entomology and Zoology Studies, 6(6), India. 2349-2368

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 - USA

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, *Build a coalition of science and industry around sorghum and millet.*

Collaborators

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

Achievements
Manuscripts were published that established baseline information on genetic diversity of pearl millet in West Africa.

Capacity building
No programs of study or trainings were conducted during this fiscal year.

Lessons learned
Population analysis determined that six subgroups overlap with the geographical origins or sources of the genotype. Considerable linkage decay indicates that a long history of recombination among landraces.

Presentations and publications

Serba, D. D. (November 2018). Genetic Diversity, Population Structure, and Linkage Disequilibrium of Pearl Millet. Presentation at ASA-CSSA Annual Meeting 2018, Baltimore, MD, USA

Serba, D. D., Muleta, K., St. Amand, P., Bernardo, A., Bai, G., Perumal, R., & Bashir, E. Genetic Diversity, Population Structure, and Linkage Disequilibrium of Pearl Millet. The Plant Genome. doi:10.3835/plantgenome2018.11.0091

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 - Senegal

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, *Build a coalition of science and industry around sorghum and millet*. 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

All project activities were completed in the previous fiscal year (2018).

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

All project activities were completed in the previous fiscal year (2018).

Presentations and publications

All project activities were completed in the previous fiscal year (2018).

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, *Build a coalition of science and industry around sorghum and millet*. 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
Manuscripts were published that describe optimal diets for rearing the parasitoid wasp that attacks the millet head minor in order to develop efficient husbandry practices for rearing. Building upon the rearing findings, the project determined the optimal timing for the release of the wasp in order to generate the highest rate of parasitism of the millet head miner.

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

The rearing and release of *Habrobracon hebetor* can be effective to augment the population of natural parasitoids against the millet head miner. Research has determined the optimal diet to feed to *Habrobracon hebetor* to rear a large enough population to reduce the economic damage caused by the millet head miner. To increase the effectiveness of the parasitism, optimal times to release the wasp were determined in relation to the physiological growth stage of the crop.

Presentations and publications

Laouali, A., Ba, M. N., Baoua, I., & Rangaswamy, M. (August 2019). 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) (pp.1-9). Biocontrol, 64(2019), Springer Netherlands. doi:10.1007/s10526-019-09960-2

Laouali, A., Baoua, I., Ba, M. N., & Rangaswamy, M. (March 2019). 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 (pp.1-5). Journal of Insect science, 19(2), Oxford Academic. doi: https://doi-org.eres.qnl.qa/10.1093/jisesa/iez020

PHASE I PROJECTS WITH PHASE 2 CONTINUATION (PHASE I FINAL REPORT AND PHASE 2 UPDATE)

PHASE I: Genetic improvement of sorghum and millet for resistance to fungal pathogens

Led by
Dr. Tesfaye Mengiste
Purdue University - USA

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

Description
The goal of this project is to enhance sorghum productivity and improve livelihood of sorghum farmers. In hot and humid regions of the world in general, in Africa and in the vast area of Western Ethiopia the prevailing conditions favor plant disease epidemics. Provided disease control measures are in place, significant increases in sorghum productivity could be achieved in these regions. Despite decades of extensive sorghum improvement work in Ethiopia, disease resistance breeding has not been a major objective of research and breeding. The current project is to identify adapted disease resistance sorghum germplasm with high yield potential and adapted to this particular ecology. Researchers are applying genetic and genomic technologies to explore the sorghum germplasm identify genes and alleles underlying fungal disease resistance specially anthracnose and grain mold which are identified as major constrains to sorghum yield and grain quality.

Vast areas of Western Ethiopia that grow sorghum are characterized by hot and humid conditions that favor plant disease epidemics but are productive by other measures. Similar sorghum production conditions occur in the US, India, and many regions of Africa. Provided disease control measures are in place, significant increases in sorghum production could be achieved in these regions. In Ethiopia, disease resistance breeding and plant pathology research has not been a major objective leaving a major gap. As a result sorghum anthracnose and grain mold, two of the most important diseases of the crop which reduce yield and grain quality, remain a challenge to productivity. The focus of the current project is to identify adapted disease resistance sorghums with high yield potential and adapted to this particular ecologies. In this first phase, the emphasis has been understanding the genetics of disease resistance, identifying resistant germplasm and resistance genes/alleles. These will lay the foundational tools and knowledge to drive improvement work in the target area and beyond. We have been leveraging advances in genetic and genomic technologies to accomplish the main objectives described.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change, *Build a coalition of science and industry around sorghum and millet*. 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* - EIAR (Asosa Research Center, Pawe Research Center, Bako Research Center), Holleta Biotechnology Center

Achievements

During this reporting period, field and laboratory experiments were conducted to accomplish project objectives. Genetic screening for disease resistance, developing disease resistant breeding population, and characterization of resistance genotypes continued. A total of 1,600 Ethiopian sorghum accessions were genotyped and analysis of the association between sequence polymorphism and the different traits are being conducted to determine loci underlying disease resistance. The availability of sequences for such a large population of Ethiopian germplasm has laid the foundation for future genetic studies in many different traits. The team also conducted nurseries for screening disease resistance. Grain mold and anthracnose resistant germplasms were identified. For a subset of these materials the genes and/or genomic regions carrying the resistance factors have been determined. Some of the resistant materials are incorporated into the sorghum breeding program in Ethiopia. Crosses were made to other adapted and high yielding materials. The species composition of the molding fungi were determined in locations in Western Ethiopia where grain mold fungi are significant problems. This knowledge will guide resistance gene identifications for future activities. Finally, this project continued to provide training for students at the PhD level at Purdue, at MS in Ethiopia and one short term training visit by an EIAR staff at Purdue.

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

Resistance against anthracnose can be conferred with the introduction of resistance genes into sorghum. Preliminary studies have identified potential sources of resistance against grain mold.

Presentations and publications

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

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

Tessema, G. G., Nida, H., Tesso, T., Ejeta, G., & Mengiste, T. (May 2019). A large-scale genome wide association analyses of Ethiopian sorghum landrace collection reveal loci associated with important traits (pp.1-15). Frontiers in Plant Science, 10, Lausanne, Switzerland. doi: 10.3389/fpls.2019.00691

PHASE 2: Genetic improvement of sorghum for resistance to fungal pathogens

Led by
Dr. Tesfaye Mengiste
Purdue University - USA

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

Description
The overarching goal of this project is to improve the livelihood of sorghum farmers in the plant disease prone regions of Ethiopia by providing disease resistant and adapted varieties that also integrate other desirable traits. This project will build on scientific discoveries, disease resistant germplasm, and networks of collaborators, established in the first phase, to deliver genotypes that integrate critical traits including wide adaptation, disease resistance and high yield potential. Resistant genotypes identified through multi-year and multi-location field trials in the first phase of this project are already incorporated into the breeding pipeline of the national and regional research institutes. Introgression of disease resistance genes into widely adapted elite materials that are deficient in diseases resistance genes is also underway. These parallel efforts will be accelerated to complete the development and release of regionally or nationally adapted varieties that integrate important traits. To support sorghum improvement in the project target region and beyond, strategic research that focuses on gene discovery and scientific advances will be conducted through genetic and genomics studies of unique resistant materials and populations we developed. Genetic resources such as adapted landraces, breeding lines and recombinant inbred populations harboring resistance to foliar and grain disease were identified and characterized. Genes underlying this traits will be identified to develop molecular marker to support improvement of the crop in Ethiopia and other countries with similar challenges. A collection of Ethiopian sorghum landrace population was partially characterized and genotype information generated. Deep phenotyping and sequencing of a core representative set of landraces, defined on the bases of genomic data, will be conducted to serve as the main source of traits for future breeding and strategic research, and lay the foundation for genomics enabled breeding platform. Finally, the project will incorporate graduate education, short term training and knowledge enhancing workshops to strengthen the human and institutional capacity of local research institutions.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change, *Build a coalition of science and industry around sorghum and millet*. 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* - EIAR (Asosa Research Center, Bako Research Center), Oromia Agricultural Research Institute, Haramaya University

Achievements
Please see the list of achievements for the phase I project as the achievements overlap with the start-up of the second phase.

Capacity building

Individuals trained under this project include two Ph.D. students from Ethiopia in plant pathology at Purdue University in the United States.

In addition, this project hosted an in-country training in August 2019 at the Melkassa research station aimed at helping researchers better utilize DNA sequence data and understand genomic approaches in crop improvement.

Lessons learned

Please see the lessons learned for the phase 1 project as the achievements overlap with the start-up of the second phase.

Presentations and publications

Girma, G., Nida, H., Seyoum, A., Mekonen, M. Y., Nega, A. (May 2019). A Large-Scale Genome-Wide Association Analyses of Ethiopian Sorghum Landrace Collection Reveal Loci Associated With Important Traits (pp.1-15). Frontiers in Plant Science, 10(691), Lausanne,Switzerland. doi: 10.3389/fpls.2019.00691

Girma, G. (August 2019). Introduction to genomics approaches and its utilization in plant breeding. Presentation at Genomic approaches in crop improvement, Melkassa, Ethiopia

Girma, G. (September 2019). Genomic characterization of Ethiopian sorghum germplasm. Presentation at Genomic approaches in crop improvement, Melkassa, Ethiopia

Girma, G. (September 2019). Introduction to DNA Sequencing. Presentation at Genomic approaches in crop improvement, Melkassa, Ethiopia

Nida, H., Girma, G., Mekonen, M. Y., Lee, S., Seyoum, A. (January 2019). Identification of sorghum grain mold resistance loci through genome wide association mapping (pp.295-304). Journal of Cereal Science, 85, West Lafayette, Indiana, USA. doi: https://doi.org/10.1016/j.jcs.2018.12.016

PHASE 1: Genetic enhancement of sorghum to promote commercial seed supply and grain market development in Ethiopia

Led by
Dr. Gebisa Ejeta
Purdue University - USA

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, *Build a coalition of science and industry around sorghum and millet.* 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
All project activities were completed in the previous fiscal year (2018).

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
All project activities were completed in the previous fiscal year (2018).

Presentations and publications
All project activities were completed in the previous fiscal year (2018).

PHASE 2: Genetic enhancement of sorghum to promote commercial seed supply and grain market development in Ethiopia

Led by
Dr. Gebisa Ejeta
Purdue University - USA

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

Description
Ethiopian sorghums have been a great source of novel genes and valuable traits for improving the sorghum crop worldwide. Modern sorghum breeders have heavily relied on the natural diversity in sorghum landraces in search of useful traits in advancing sorghum as a feed crop in major economies, particularly in the Americas and Australia. Unfortunately, sorghum improvement in Africa lags far behind the successes that the crop has enjoyed in these other geographies. It is possible that modern research advances made on sorghum improvement in these advanced economies may benefit current and future sorghum research efforts in Africa.

This project proposes to employ tools of biotechnology, breeding, and agronomy to unleash the potential of the crop for needy farmers. They will work as members of a team in developing a core-set of sorghum germplasm population to characterize the inherent variability through genotyping by sequencing. The team will couple that with phenotyping of valuable traits under target environments, and treating data with appropriate bioinformatics and statistical procedures to identify useful allelic variations for drought and Striga resistance. They will develop local capacity and restore rigor and discipline to the Ethiopian sorghum breeding program to produce superior sorghum cultivars on a regular basis.

The project aims to develop a functional sorghum breeding program in Ethiopia focused on the development of adapted, high yielding sorghum hybrid cultivars for broad societal impact. They will promote the use of hybrid cultivars to strengthen the seed supply value chain and catalyze the development of a commercial sorghum seed enterprise system in the country. Building a commercial value chain system for sorghum in Africa is among the most badly needed investments in Africa.

Theory of change and impact pathways

All research projects contribute towards *Objective I* of our theory of change, *Build a coalition of science and industry around sorghum and millet*. 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 drought-resistant, food grain sorghum hybrid was released in Ethiopia. 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 verify/ascertain the superiority of the hybrid based on how it does under large plot on-farm testing at several locations.

Capacity building

An in-country training was completed under this project in September 2019 at the Melkassa research station aimed at helping researchers better understand genomic approaches in crop improvement.

Lessons learned

None reported.

Presentations and publications

Legesse, A. (July 2019). Performance evaluation and participatory variety selection of sorghum in the lowland areas of north shewa. Regional completed research activity forum, Bahir Dar, Ethiopia

PHASE 1: Improving sorghum adaptation in West Africa with genomics-enabled breeding

Led by
Dr. Geoffrey Morris
Kansas State University - USA

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, *Build a coalition of science and industry around sorghum and millet*. 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

Capacity development of two key junior scientists is nearing completion and their dissertation research will contribute considerable information to national programs in Niger and Senegal. In each of these countries, continued emphasis on developing stronger genotyping platforms will improve the effectiveness of genetic information contributed to breeding programs.

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

Developing high quality genetic information and testing of markers has been slow because it is important for markers and scripts to be well validated prior to release. his prevents substandard tools from being released that could become distractions to plant breeders.

Presentations and publications

Faye, J. M., Maina, F. A., Hu, Z., Fonceka, D., Cissé, N., & Morris, G. P. (May 2019). Genomic signatures of adaptation to Sahelian and Soudanian climates in sorghum landraces of Senegal (pp.1–14). Ecology and Evolution, 9(10), London, UK. doi:10.1002/ece3.5187

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

Ousseini, A. (April 2018). Traditional control of striga hermontica in Niger. Presentation at Sorghum in the 21st Century, A Global Conference, Cape Town, South Africa

PHASE 2: Improving Sorghum Adaptation in West Africa with a Genomics-Enabled Breeding Network (SAWAGEN)

Led by
Dr. Geoffrey Morris
Kansas State University - USA

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

Description

Challenge: Despite some important successes in sorghum breeding in West Africa, the overall impact of sorghum improvement has not yet met stakeholder expectations on varietal adoption, increased farm income, or improved nutritional status. SAWAGEN brings existing R&D capacity together into a network to regularly deliver sorghum varieties that are adapted to West African environments, adopted by smallholder farmers, and appreciated by value-chain actors.

Approach: The SAWAGEN network brings together NARS breeders, NARS researchers, international collaborators, and farmer organizations. To align missions and leverage expertise among diverse scientists and stakeholders, we use a goal-directed hypothesis-driven (GoHy) method for program planning and adaptive management. At the core of the network are four early-career NARS breeders in Senegal (ISRA), Burkina Faso (INERA), Togo (ITRA), and Niger (INRAN), who were trained in genomics-enabled breeding during phase-I (SMIL and/or WACCI).

Products: SAWAGEN's top priority is to develop new versions of locally-preferred varieties that carry stress-resilience traits by the project's end in 2023. Each NARS breeder has identified 2–3 product concepts that will be delivered to smallholders within a 5–10 year time frame. The varieties will be under testing in farmers' fields - in partnership with farmer organizations - by 2023. SAWAGEN's other major product is the R&D network itself, with four platforms designed to scale beyond the current participants and beyond the end of the project.

Implementation: Varietal development will be carried out in the Local Adaptation Breeding Platform with marker-assisted backcross of known stress tolerance alleles into locally-preferred varieties and participatory evaluation. The foundation for delivery of future products will be laid with the Broad Adaptation Breeding Platform (gender-responsiveness training, germplasm exchange, recurrent population development, multi-environment trials); the Genetic Mapping Research Platform (genome-wide marker discovery, genetic mapping, marker development); and the Physiological Mapping Research (trait discovery, trait validation, ideotype definition).

Theory of change and impact pathways

All research projects contribute towards *Objective I* of our theory of change, *Build a coalition of science and industry around sorghum and millet*. 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):	*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)
Burkina Faso - Institut de l'Environnement et de Recherches Agricole (INERA)
Togo - Institut Togolais de Recherche Agronomique (ITRA)
France - Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)

Achievements

Please see the lessons learned for the phase 1 project as the achievements overlap with the start-up of the second phase.

Capacity building

Individuals trained under this project include two Nigerien Master's students in crop physiology at the Universite Abdou Moumouni Niamey in Niger.

Also under this project, a short-term training in phenotyping for drought tolerance was completed with a scientific officer from Burkina Faso.

Lessons learned

Please see the lessons learned for the phase 1 project as the achievements overlap with the start-up of the second phase.

Presentations and publications

Hamidou, F. (June 2018). Field and Lysimeter phenotyping for drought tolerance in peanut and Millet and Sorghum. Presentation at Plant breeding for Drought tolerance, Colorado State University

PHASE 1: Trait development pipeline for food and feed value in sorghum

Led by
Dr. Mitchell Tuinstra
Purdue University – USA

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, *Build a coalition of science and industry around sorghum and millet.* 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
Two students from West Africa completed their doctoral degrees in plant breeding and were hired by the national programs in their countries, INRAN and CERAAS. A large collection of sorghum breeding lines segregating for the highly digestible protein traits were developed at Purdue. Seeds of the F_3 populations were received at CERAAS from Purdue University on June 25th, 2019. These populations were planted at CNRA research station (Bambey) on September 13, 2019 for seed increase and to initiate backcrosses into Senegalese elite lines. A breeding program was

initiated to backcross the hl into the elite food-grade sorghum varieties ISRA 621A, ISRA 622A, and ISRA 622B. The BC_3F_5 were planted in Bambey on September 13th, 2019 to be advanced in BC_3F_6. Field nurseries have been installed at Kollo and Maradi in Jully 2019 for *bmr* OPVs, Sudangrass hybrids and Photoperiod sensitive hybrid.

Capacity building

Individuals trained under this project include:

Elisabeth 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

A few pieces of laboratory equipment need to be ordered to support plant tissue and seed processing activities at CERAAS. Collaborative activities with INRAN have supported by complementary investment by the Nigerien government and this has increased the effectiveness of the program.

Presentations and publications

Diakite, O. Breeding Sorghum [Sorghum Bicolor (L.) Moench] for High Quality Stover for Niger

Griebel, S., Webb, M. M., Campanella, O., Craig, B., Weil, C., & Tuinstra, M. (January 2019). The Alkali Spreading Phenotype in Sorghum bicolor and its Relationship to Starch Gelatinization (pp.41-47). Journal of Cereal Chemistry, 86, Amsterdam, The Netherlands. https://doi.org/10.1016/j.jcs.2019.01.002

Griebel, S., Westerman, R., Adeyanju, A., Addo-Quaye, C., Craig, B. Mutations in sorghum SBEIIb and SSIIa affect alkali spreading value, starch composition, thermal properties and flour viscosity. Theoretical and Applied Genetics

PHASE 2: Sorghum Trait Deployment Pipeline for Improved Food and Feed Value

Led by

Dr. Mitchell Tuinstra
Purdue University – USA

Location (department level)

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

Description

This proposed project expands the team's sorghum crop improvement efforts through targeted research and technology transfer to promote and enhance sorghum production and nutritional value. Researchers have already identified allelic variation in genes that influence grain and forage quality; specifically grain protein digestibility, modified starches that produce new functional food and nutritional attributes, and improved forage quality.

The Protein Digestibility Lab established in Senegal will serve as a hub of activity in West Africa for efforts to develop sorghum cultivars with improved post-cooking protein digestibility. As new varieties are developed, ISRA will engage

with sorghum farmers and end-users to evaluate the bread-making and couscous-making qualities of grain produced using these varieties as well as their feed value in poultry rations.

A Forage Sorghum Breeding Program will be established at the INRAN Kollo Research Station. The bmr6 and bmr12 alleles will be used to develop new forage varieties in the El Mota and SEPON82 backgrounds. Hybrid forage varieties will be developed using locally-adapted seed and pollinator parents. AN223 and selected A-lines from the breeding program will be crossed with elite forage and Sudangrass pollinators being developed at Purdue.

The crop development activities described in this proposal will produce new and unique sorghum varieties and hybrids with enhanced food- and feed-quality traits. Farmer participation during evaluation and selection of the best new varieties will promote acceptance and production of new cultivars. Researchers will also work with seed system specialists to encourage and enable seed production and distribution. Increased production and availability of high-quality seeds and grains will stimulate and support the development of new markets.

Theory of change and impact pathways

All research projects contribute towards *Objective I* of our theory of change, *Build a coalition of science and industry around sorghum and millet.* 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

Please see the lessons learned for the phase I project as the achievements overlap with the start-up of the second phase.

Capacity building

Under this project in FY 2019, Elisabeth Diatta, a Senegalese Ph.D. candidate, and Ousmane Seyni, a Nigerien Ph.D. candidate, completed their training and defended their dissertations at the West Africa Centre for Crop Improvement at the University of Ghana prior to returning to their home institutions for continued employment.

Lessons learned

Please see the lessons learned for the phase I project as the achievements overlap with the start-up of the second phase.

Presentations and publications

Diatta, E. Genomic study and genetic improvement of sorghum [Sorghum bicolor (L) MOENCH] for high protein digestibility

Diatta, E., Tuinstra, M., Cisse, N., Weil, C., Tongoona, P..... Towards Developing High Lysine-Highly Digestible Sorghum Varieties After Wet Cooking

Diatta, E., Tuinstra, M., Weil, C., Cisse, N., Danquah, E., Tongoona, P., & Danquah, A.. Identification of Genomic Loci Controlling High Protein Digestibility in Sorghum Grain

PHASE 1: 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 – Germany

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, *Build a coalition of science and industry around sorghum and millet.* 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
At the time of reporting, conducted field trials are not yet harvested. Soil samples were collected from 34 seedball on-farm trials in eastern Niger (Maradi region). With respect to the study of combined effects of seedballs and post-emergence fertilization 18 trials were successfully installed. A prototype of a mechanized seedball production machine was developed to 90%. Testing is envisaged for October/November 2019. Animator training was successfully conducted in both regions (1.1). Farmer training was also conducted but in lower numbers (total 54, from which 20 women) than planned (1.2). With respect to Mooriben in SW-Niger 2 female and 10 male farmers were trained. Training in the

Maradi region (Fuma Gaskiya) reached 18 female and 24 male farmers. Activities 1.3 and 1.4 are not due in this reporting period.

Capacity building
Individuals trained under this project include:

Iro Ousseini	INRAN	Bachelor's	Agronomy
Daouda Abassa	INRAN	Master's	Socio-economy
Lena Geiger	INRAN	Master's	Agronomy/soil science
Charles Nwankwo	University of Hohenheim	Ph.D.	Agriculture

Lessons learned
The seedball technology turned out to be technology that is preferred by female farmers. So no specific promotion is necessary to attract women to take part in seedball activities. Nevertheless gender-sensitive training was provided.

Presentations and publications
Nwankwo, C. I., SY, O., & Herrmann, L. (January 2019). Physical and chemical optimisation of the seedball technology addressing pearl millet under Sahelian conditions (pp.67-79). J. Agric. Rural Development in the Tropics and Subtropics, 119/2, Kassel, Germany. doi.org/10.17170/kobra-2019011596

PHASE 2: Seedballs - Enhancing the yield effect in pearl millet and sorghum and disseminating the technology in West Africa

Led by
Dr. Ludger Herrmann
University of Hohenheim – Germany

Location (department level)
Niger - Aguie

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.

The project builds on the previous activities in phase I to pursue 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 team wishes to further research, develop and disseminate the seedball technology in Niger. The research component addresses application to sorghum and combination with other yield enhancing innovations (e.g. fertilizer-micro-dosing). The development aspect is dedicated to mechanization. Dissemination is based on collaboration with farmer federations (Fuma Gaskiya, Moorigen) in Niger. The latter is accompanied by a research component that surveys adoption pre-requisites and constraints.

Theory of change and impact pathways

All research projects contribute towards *Objective I* of our theory of change, *Build a coalition of science and industry around sorghum and millet*. 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): *Niger* - INRAN, Fuma Gaskiya (farmer organization), FUGPN Mooriben (farmer organization)

Achievements

Please see the lessons learned for the phase I project as the achievements overlap with the start-up of the second phase.

Capacity building

No major capacity building activities have yet occurred as this project is currently in early stages of research activities.

Lessons learned

Please see the lessons learned for the phase I project as the achievements overlap with the start-up of the second phase.

Presentations and publications

Nwankwo, C. I. Seedball technology development for subsistence-oriented pearl millet production systems in Sahelian West Africa

Nwankwo, C. I., Moussa Oumarou, H. M., Maman, N., Maman Aminou, A., & Herrmann, L. (August 2019). Seedball technology enhances early seedlings establishment and yield of pearl millet crop in subsistence production system in W. African Sahel. Joint National Conference of the German and Suisse Soil Science Societies, Bern, Switzerland

Nwankwo, C. I., Moussa Oumarou, H. M., Maman, N., Maman Aminou, A., & Herrmann, L. Seedball technology enhances yield of pearl millet in a Sahelian subsistence production system. Field Crops Research.

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

Led by
Dr. Joseph Awika
Texas A&M University - USA

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, *Build a coalition of science and industry around sorghum and millet*. 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
Researchers have produced a minimum of 600 kg of the advanced sorghum hybrids for products testing. The sorghum is being prepared at Texas A&M for shipment to Ethiopia (500 kg x 4 varieties) for initial technology development and product testing. Thirty experimental lines are being field tested in two locations in Ethiopia. Malting performance of

improved sorghums relative to commercial sorghums established. A final project training on sorghum-based food processing technologies and their quality evaluation was conducted at Hawassa in February 2019. Key representatives from the food industry, government and academic institutions participated. Fourteen individuals participated.

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

In addition, two short-term trainings on sorghum food processing and quality as well as sorghum malting and brewing were conducted in Ethiopia.

Lessons learned

A lot of excitement generated among small and medium scale food processors. It will be important to follow through with adequate supply of quality grain for large scale product testing in a timely manner. Training targeted key decision-makers in the various sectors; females are underrepresented in such leadership levels, thus gender parity was below a target of 50%.

Presentations and publications

Mezgebe, A. G. (July 2019). Sorghum waxy (high amylopectin) and high protein digestibility (HD) traits and their relationship in injera and biscuit making quality. 13th Pangborn Sensory Science Symposium, Edinburgh, Scotland

Mezgebe, A. G. Sorghum waxy and high protein digestibility traits and their relationship with malting and dough-based product making quality

Ncube, M. (September 2019). Model gluten-free bread doughs made with sorghum and maize prolamin proteins (kafirin and zein) and non-wheat starch. South African Association for Food Science and Technology Congress, Johannesburg

Taylor, J. (April 2019). A step closer to gluten-free bread made with non-wheat prolamin proteins that replace gluten functionality. 19th International Association for Cereal Science and Technology Conference, Vienna, Austria

Taylor, J. (May 2019). Tropical cereal grains as raw materials for brewing in Africa and for gluten-free brewing. What's Brewing in Africa, Addis Ababa, Ethiopia

Teferra, T. Effect of combining highly digestible protein and waxy starch traits on sorghum endosperm functionality and protein digestibility

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.

PHASE 2: Advancing improved functionality and protein quality sorghum hybrids for food applications in Ethiopia

Led by
Dr. Joseph Awika
Texas A&M University - USA

Location (department level)
Ethiopia – Sidama

Description
New sorghum hybrids under development combine high protein digestibility (HPD) mutation with waxy and heterowaxy (WX/HX) starch traits in hard endosperm show a lot of promise for various food applications due to superior functionality and improved protein nutritional quality. This project aims to advance the use of these new sorghums for food and nutrition security in Ethiopia. Based on the key findings from phase I, the research team proposes to: 1) Develop commercially viable technologies to successfully incorporate the improved sorghums in various food processes and products in Ethiopia; and 2) Establish improved HPD sorghum hybrid seed and grain production in Ethiopia. Based on phase I findings, researchers expect that the improved sorghum hybrids can be successfully incorporated in mainstream food processing value chain to produce commercially competitive products that meet quality expectations of a broad consumer base in Ethiopia. They also expect to demonstrate that the improved sorghum hybrids will compete favorably with local hybrids in both high input and low input environments in Ethiopia. This will likely lead to a more rapid incorporation of these hybrids into local sorghum breeding and seed production systems targeting specific market applications. Addressing these objectives will lead to development of commercially viable, superior quality sorghum-based food products that will open new markets and enhance sorghum value-chain. This will benefit small-scale farmers who dominate sorghum production, and small and medium scale food enterprises (SMEs) a large portion of which are female-owned. Additionally, increased utilization of HPD-sorghums in local products would significantly contribute to reduced malnutrition in children from regions that rely on sorghum as a staple.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change, *Build a coalition of science and industry around sorghum and millet.* 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, Ethiopian Institute of Agricultural Research (EIAR)

Achievements
Please see the lessons learned for the phase I project as the achievements overlap with the start-up of the second phase.

Capacity building
No major capacity building activities have yet occurred as this project is currently in early stages of research activities.

Lessons learned
Please see the lessons learned for the phase I project as the achievements overlap with the start-up of the second phase.

Presentations and publications

No presentations or publications have yet been produced as this project is currently in early stages of research activities.

Senegal - Dakar
Burkina Faso - Kaya

PHASE I: 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 – USA

Location (department level)
Niger - Niamey, Tera, Tchirozerine, Magaria

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, *Build a coalition of science and industry around sorghum and millet.* 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
At ITA, progress was made on the new sensory laboratory. A building at the ITA Dakar campus was identified and given for renovating for the sensory laboratory. Design construction drawings were made, sourcing of equipment done, and

contract work completed. The sensory laboratory is expected to be completed in spring 2020. At INRAN Niger, a student was identified from University of Tillabery, with whom M. Moussa was an advisor, and began working at the Hub Food Innovation Center in Niamey to learn processing technologies. Improved formulated porridge flour blends (both roasted and extruded instant) were found to have higher iron contents than locally available food aid flour blends. Pro-vitamin A carotenoids and lutein were generally bioaccessible in the fortified flours.

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

The nutritionally improved flours that have been formulated for local tastes and preferences will be assessed for their market potential with mothers and their children, and nutritional benefit examined to ensure potential demand.

Presentations and publications

Debelo, H., Corbin, S., Chegeni, M., Ferrara, F., Valacchi, G., & Ferruzzi, M. (April 2019). Repeated Exposure of Native African Adansonia Digitata (Baobab) and Moringa Oleifera (Moringa) Modifies Caco-2 Cell Differentiation but Not Carotenoid Absorption. Nutrition 2019, Baltimore, MD, USA

Debelo, H., Kruger, J., Hamaker, B., & Ferruzzi, M. African Adansonia digitata (baobab) modifies provitamin A carotenoid bioaccessibility but not uptake by Caco-2 human intestinal cells from composite pearl millet porridges. Journal of Food Science and Technology

Dieme, E., Diop, M., Ndiaye, C., Sarr, I., Seydi, M., & Traore, D. (January 2019). Critical Periods of Aflatoxin Contamination of Maize during Post-Harvest Management in Velingara(pp.6). Journal of Nutritional Health and Food Science, 7(1):1-6, Dakar Senegal. ISSN 2372-0980

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

Dieme, E., Traore, D., Sarr, I., Ndiaye, C., & Diop, M. Aflatoxin management in Senegalese processing units. Journal of Nutritional Health and Food Science

Hayes, A., Swackhamer, C., Mennah-Govela, Y., Martinez, M., Diatta, A., Bornhorst, G., & Hamaker, B. Pearl millet (Pennisetum glaucum) couscous breaks down faster than wheat couscous in the Human Gastric Simulator, though has slower starch hydrolysis. Food & Function

Moussa, M., Hamaker, B. R., A. P., & Campanella, O. Innovative way of making millet and sorghum couscous by using a single screw mini-extruder

Moussa, M. & Hamaker, B. (September 2018). Hub-and-Spoke Food Processing Innovation System. Presentation at Scale up conference Purdue University Sept 2018, Purdue University, West Lafayette, IN, USA

Moussa, M. & Hamaker, B. (October 2018). Diversification de l'Utilisation des Grains de Légumineuses et Céréales par la Transformation pour Améliorer la Nutrition et Etendre les Marchés en Afrique de l'Ouest. Presentation at Journée Mondiale de l'Alimentation (JMA,) 2018, INRAN, Niamey, Niger

Moussa, M., Liman Issaka, A., & Bruce, H. (February 2019). PRESENTATION/Scaling UP de l'entreprise de transformation des céréales (ETC) – Niger a L' Atelier Régional de Clôture du Programme sur le Commerce Transfrontalier des Produits Céréaliers en Afrique de L'Ouest (WAFM)/UKAID,. Presentation at Atelier Régional de Clôture du Programme sur le Commerce Transfrontalier des Produits Céréaliers en Afrique de L'Ouest (WAFM), Africa Regent Hotel, Accra – Ghana

Moussa, M., Hamaker, B. R., & Ba, F. (February 2019). Project Transformation: Mon Project en relation avec mon favoris cadre IAE. Presentation at Mcknight 2019 CCRP West Africa Community of Practice (CoP) meeting, Location: Hotel Mande, Bamako, Mali

Moussa, M. & Hamaker, B. (March 2019). Technology Show Case, Processing Project. Presentation at SMIL Phase II project launch meetings on March 26-28, 2019 at Le Grand Hotel du Niger in Niamey, Niger. Grand Hotel du Niger in Niamey, Niger

Moussa, M. (May 2019). Fortifying Millet Grain with Legumes and Natural Fortificants, A Sustainable Market-Driven Model to Improve Nutrition in West Africa. Presentation at Whisler Center for Cabohydrate Research Annual Meeting, Purdue University, West Lafayette, IN, USA

N'Diaye, C., Martinez, M., Hamaker, B. R., & Ferruzzi, M. Effect of edible plant materials on provitamin A stability and bioaccessibility from extruded whole pearl millet (P. typhoides) composite blends.. LWT - Food Science and Technology

Ndiaye, C. & Ndiaye, A. (November 2018). Market development on producing economic couscous and its promotion. Doctorials of Cheikh Anta Diop University, Dakar-Senegal

Sene, A. (November 2018). Production of instant "arraw", a rolled flour millet based product well prized by the Senegalese population and overseas. Doctorials, Dakar-Senegal

PHASE 2: Expanding markets for sorghum and millet farmers in West Africa through strengthening of women and youth processors and nutrition-based promotion of products

Led by
Dr. Bruce Hamaker
Purdue University – USA

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

Description
In Phase 2, the focus of this project will be on resilience of the Hub Food Innovation Centers as convergence points for product innovation and drivers of economic and nutritional impacts for Niger and Senegal. Hub Food Innovation

Centers will be strengthened to better engage with entrepreneurs, improve their effectiveness as product development centers, and bolster their sustainability. Process and product innovation of millet and sorghum foods will be enhanced by expansion of "next level" product development tools including sensory science capacity, packaging, and shelf-life assessment. These tools will enhance their support for entrepreneurs and solidify INRAN and ITA as regional R&D centers. Activities will strengthen sensory science capacity at ITA Senegal to "raise the bar" of their product development capacity and establishing their potential as a regional center of development, will complete and optimize food processes and products begun in Phase I in Niamey and Dakar to include: 1) varietal optimization in traditional and new product concepts, 2) expanded product/process optimization to include packaging and shelf-life assessment, 3) training of candidate youth from local universities, 4) facilitate youth and existing women entrepreneur processors by allowing them to use the Hub processing facilities on a fee-basis, and market products. A study will be conducted to test the hypothesis that nutritional status improvement can be achieved in rural communities in Niger through introduction of low-cost fortified millet-based foods designed with local ingredients and aligned with documented preferences of local consumers. The Hub-and-Spoke Food Innovation System will test formulations developed from Phase I activities as well as develop new high quality, safe, and nutrient-enhanced millet products using local nutrient-dense plant ingredients for food-to-food fortification, and show if these locally produced products will gain a market and additionally be preferred to imported food-aid blends facilitating improved adoption by rural children in Niger.

Theory of change and impact pathways

All research projects contribute towards *Objective I* of our theory of change, *Build a coalition of science and industry around sorghum and millet*. 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

Please see the lessons learned for the phase I project as the achievements overlap with the start-up of the second phase.

Capacity building

No major capacity building activities have yet occurred as this project is currently in early stages of research activities.

Lessons learned

Please see the lessons learned for the phase I project as the achievements overlap with the start-up of the second phase.

Presentations and publications

No presentations or publications have yet been produced as this project is currently in early stages of research activities.

NEW PHASE 2 PROJECTS

Genetic Enhancement of Pearl Millet for Yield, Biotic and Abiotic Stress Tolerance in West Africa (GENMIL)

Led by
Dr. Ndjido Kane
Institut Sénégalais de Recherches Agricoles (ISRA)/CERAAS - Senegal

Location (department level)
Niger – Niamey
Senegal – Thies, Bambey

Description
Drought, diseases and insects are key constraints for millet production in West Africa. There is a recognized need for rapid advancement in the development of varieties addressing these constraints and taking into consideration farmer's practices and market acceptability. This project aims to accelerate the development of a combination of pearl millet (PM) innovations to put into farmers hands that at finite will result in sustainable productivity enhancement of PM for food security and income generation. Specific objectives are: i) modernizing INRAN and ISRA breeding program to deliver high-yielding PM cultivars that tolerate drought, Striga and downy mildew in Niger and Senegal; ii) assisting production with adapted and resilient farmer's practices and crop management strategies; iii) co-developing and up-scaling selected options of integrated genetic, natural resource management context to improve PM production; and iv) empowering human and institutional capacities.

The five-year research project (2019-2023) is compartmentalized to meet these 4 specific objectives, relying on series of activities and strategic criteria. A first criterion is dialogue between scientists and farmers and back-and-forth with end-users for a high rate of adoption of PM innovations. The activities around will consist of promoting adoption and advocating the uses and benefits of new PM technologies, within an innovative platform gathering actors of the value chain (stakeholders, private sector, farmer's organizations, extension services, scientists). Sharing material and knowledge will bring on germplasm originating from West Africa, from Niger and Senegal. Genetic materials either available or being developed will be shared between teams and research programs. Breeding Management System (BMS) will be used as standardize unique management and sharing resources (plant materials and data) system. Germplasm will be evaluated in both Senegal and Niger. Inter population improvement approach of reciprocal recurrent selection (RRS) method will be applied using selected populations to make use of both general and specific combining ability. Recent phenotyping and genotyping approaches will be conducted to evaluate the germplasm and identify/validate major quantitative traits loci (QTLs) for tolerance to drought, resistance to major biotic stresses in Senegal and Niger (complementary and co-working). Farming practices coping with diseases or ecologically intensifying production will be added into the breeding product profile (co-conceptualization). All identified elite cultivars will be integrated into local breeding programs (co-breeding) and evaluated on-farm for performance and farmer/market acceptability (scaling-up). Mentoring of early career research and continuous empowering of young trainees (PhD an MSc), farmers and seed producers will contribute to human and institutional capacity building needed to modernize sustainable PM breeding programs across the NARIs.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change, *Build a coalition of science and industry around sorghum and millet*. 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* - Institut Sénégalais de Recherches Agricoles (ISRA), Centre d'Etudes Régional pour l'Amélioration de l'Adaptation à la Sécheresse (CERAAS)
Niger - International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Institut National de la Recherche Agronomique du Niger (INRAN)

Achievements

Key actors already working and involved in different production system and value chain gathered, such as ANCAR, RESOPP and PSEM-CLUSA. Researchers shared hybrid and open pollinated varieties with farmer organizations for farmer fields' evaluation to collect quantitative and qualitative data and to identify some preferences to into the minimal value product (MVP). A total of 8 trials were started including with farmers and extension agencies promoting hybrids and OPVs. At ICRISAT SADORE, populations of BCNAM are being advanced, crosses for hybrids development also made. Genetic resources were shared with Senegalese team.

Capacity building

As a part of this project's initial activities, two short-term trainings were offered in Niger during FY2019 – one of those was targeted to farmers around hybrid seed production and the second was targeted at students to improve scientific rigor in their research.

Lessons learned

In Senegal, timing of the activities during rainy season was very difficult to meet/gather actors during this busy period, will have to delay later this year. In Niger, seedling of baby trial at four sites in Maradi; in Dosso it was not possible to install the test due to lack of means.

Presentations and publications

No presentations or publications have yet been produced as this project is currently in early stages of research activities.

Enabling Marker Assisted Selection for Sorghum Disease Resistance in Senegal and Niger

Led by
Dr. Clint Magill
Texas A&M University - USA

Location (department level)
Niger – Niamey
Senegal – Thies, Bambey

Description
Research collaboration between Texas A&M, INRAN, and ISRA, extended to include researchers at nearby Universities in Niger and Senegal will result in the identification or creation of disease resistant, locally adapted, sorghum cultivars that maintain properties preferred by farmers and consumers alike. Target diseases are anthracnose and long smut in Niger and anthracnose and grain mold in Senegal. The cultivar creation aspect will be derived from the ability to track resistance genes or quantitative trait loci (QTLs) with DNA-based tags that can be economically scored, in-country, through the development of allele-specific PCR primers at TAMU. Marker tagging will use Genome Wide Association studies to identify Single Nucleotide Polymorphisms (SNPs) derived from sources of genetic resistance identified in each country. F2 or later generation DNA samples from resistant and susceptible progeny of segregating crosses will identify markers associated with disease response. This technology will enable breeders to take advantage of marker assisted selection to greatly speed the development of cultivars with resistance to new races of the pathogens that are certain to occur over time. Publications in scientific journals will inform other scientists interested in sorghum pathology and genomics while demonstrations and interactions with local farmers unions, including sorghum growers, will showcase the value of growing disease resistant cultivars.

Theory of change and impact pathways
All research projects contribute towards *Objective I* of our theory of change, *Build a coalition of science and industry around sorghum and millet.* 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, USDA-ARS
Intl. collaborating institution(s):	*Senegal* - Institut Sénégalais de Recherches Agricoles (ISRA), Centre d'Etudes Régional pour l'Amélioration de l'Adaptation à la Sécheresse (CERAAS) *Niger* - Institut National de la Recherche Agronomique du Niger (INRAN), University of Tillaberi

Achievements
Conducted disease surveys in principle sorghum growing areas. Surveys will be made in at least two years using standard "X or W" sampling schemes within each field. Geo references will be taken where possible and cultivars identified will be noted. Collected samples of infected leaves/grain for fungal isolation. During the surveys, anthracnose infected leaves were sampled from each of the designated areas. One hundred isolates from each country, selected from different host cultivars and locations will be collected for use in later activities. Drs. Issa Adamou (Université of Tillabéri), Issa Karimou and Haougui Adamou (INRAN) are growing 19 sorghum cultivars primarily from the U.S. that are frequently used as host-differentials for disease screening at Tiliberi and Maradi.

Capacity building

One Nigerien Master's student is being trained under this project in plant pathology/breeding at the University of Tillabery in Niger.

Lessons learned

It is difficult to do accurate diseases assessment in the greenhouse when the temperatures are as high as they were this summer. Researchers have installed a misting system and are hopeful that will allow accurate identification of susceptible lines. Live samples cannot be received via APHIS regulations, meaning any samples sent from Africa will either need to be extracted DNA or from spores collected in alcohol.

Presentations and publications

Mame, S. P. (August 2019). Utilisation de la sélection assistée par marqueurs pour la résistance aux maladies du sorgho au Sénégal et au Niger. Scientific Days on National Center for Agronomic Research, Bambey, 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, *Build a coalition of science and industry around sorghum and millet*. 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

Overall, the research team has showed that genomic selection can be performed in a low budget developing world breeding program. The technologies enabling it have been developed at Cornell and they have achieved an <10 USD per sample for accurate genotyping and Chibas has worked on the breeding methodology.

The team's simulation study (Kebede et al, 2019, G3: Genes, Genomes, Genetics, 9(2), 391-401.) suggests that with these achieved costs, genomic selection should achieve a faster genetic gain at a cheaper cost per unit of genetic gain. Evaluation of the first advanced inbred lines coming out of their genomic selection cycles (4 cycles to date) are currently underway.

The technology used for sequencing sorghum plants allowed the team to achieve excellent prediction accuracy (e.g., mean correlation between predicted and observed values above 0.5 across all trials, for grain yield).

The practical haplotype graph, a software for sequencing many samples at very low cost, has been developed and tested in the Chibas populations (founders and training set). In a study recently submitted and currently available as preprint

(http://dx.doi.org/10.1101/775221), they have shown that this imputation method achieved imputation accuracy similar or higher than standard methods, especially for sequencing many samples (low-depth sequencing).

Specific institutional achievements include:

CORNELL

1. Researchers have developed the technologies and pipeline to efficiently extract DNA and genotype sorghum plants for less than 10 USD per sample, using to dry leaf punch in 96-well plates.
2. Sorghum plants were sequenced using rhAmpSeq, a targeted sequencing technology which was cost-effective and yielded high-quality sequencing data at thousands of sites (1740 to 3047 single-nucleotide polymorphisms).
3. The practical haplotype graph has been developed and tuned for accurate genotyping in the Chibas populations. Researchers have constructed the database used to store variants of gene regions across Chibas founder lines.
4. Researchers have developed a pipeline to extract similarity about gene regions as alternative genomic information, and proved the usefulness of this approach in genomic selection.

HAÏTI - Chibas

1. Researchers have completed 4 cycles of genomic selection while performing one cycle of phenotypic S1 selection.
2. The first advanced lines produced from genomic selection are under evaluation.
3. Researchers have fine mapped the male sterility ms3 gene.
4. With the Geoffrey Morris lab at Kansas State University, researchers have fine mapped the SCA resistance gene (sorghum sugarcane aphid) and have developed markers for it.
5. Morris' lab has validated the SCA markers in an independent population.
6. Researchers have characterized the GxE and wide adaptation (good performance across environments) and low ecovalence (stable yield across environments). Both are heritable and can be selected for by genomic selection. This is certainly one of the major advantages of genomic selection as in traditional phenotypic breeding, selection for wide adaptation and yield stability is very costly.
7. Researchers have showed that staygreen contributes to yield stability across environments.
8. Three new inbred lines (from populations developed before the start of the project) have been selected from the project multilocation trials for their broad adaptation and yield stability across environments.
9. Two Haitian Master students have now completed their Master thesis with partial support and using data generated by the project: Jean Rigaud Charles (Master from the school of Agriculture of Montpellier, France) and Marie Darline Dorval (Master from University of Florida, USA).
10. Two new sugarcane aphid resistant varieties were promoted to pre-release status in Haiti.

Capacity building

Individuals trained under this project include:

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

In addition, one short-term training for Charles Rigaud on sorghum practical haplotype graph was provided at Cornell University.

Lessons learned

The project research team indicated the following lessons learned:

- Long tail distribution (especially on the low performance end) of the GS population; possibly epistasis – initial results, work underway
- Looking for an alternative to ms3 to perform the crosses; testing chemical induction of male sterility developed by TAMU

- Work has been very useful to characterize the genetic diversity and agronomic performance of the Chibas germplasm and is helping us to make better decisions on where to take the program in the future
- Three new inbred lines (from crosses and populations made before the start of the project) have been selected during project and selected using data generated by the project (selected for broad adaptation and yield stability); indirect benefits of the project
- Team is getting better at turning in genotyping data "on time" (still some technical challenges to be solved for smoother processes)
- The practical haplotype graph can be very accurate for genotyping sorghum plants at low cost, but it requires proper tuning of imputation parameters ("consensus threshold" used for condensing haplotypes at gene regions).
- The practical haplotype graph can be used for dense marker assay and imputation, which will be critical for subsequent detection of deleterious variants and characterization of mutation load at gene regions.
- There are considerable constraints to exchanging germplasm between low income countries and the United States that limits the speed and efficiency of collaboration.

Presentations and publications

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

Jensen, S. (October 2018). Jensen Lightning Talk. Presentation at Cornell Institute of Biotechnology Open House, Ithaca, NY

Jensen, S. (December 2018). "What has Sarah been doing for the last month?" Presentation to ICRISAT hosts at end of month long visit, Hyderabad, India

Jensen, S. E. (January 2019). The Practical Haplotype Graph: Cheap genomic selection using a pan-genome database with diverse taxa. Presentation at PAG 2019, San Diego, CA

Jensen, S. (April 2019). The Practical Haplotype Graph: Cheap genomic selection using a pan-genome database with diverse taxa. Presentation at Kansas State University, 4th Plant Breeding and Genetics Symposium, Manhattan, KS

Jensen, S. (April 2019). When do we need a Practical Haplotype Graph? Presentation at Cornell Plant Breeding and Genetics Student Seminar, Ithaca, NY

Morris, G. P., Pressior, G., & Muleta, K. T. (February 2019). Optimizing genomic selection for a sorghum breeding program in Haiti - a simulation study (pp.391-401). G3: Genes, Genomes, Genetics, 9(2), Bethesda, MA. doi:10.1534/g3.118.200932

Muleta, K. T., Pressoir, G. H., Morris, G. P., & Felderhoff, T. Recent evolutionary rescue of sorghum in the Americas required sixty years of global germplasm exchange. The Plant Genome

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

Human and Institutional Capacity Development

Human and institutional capacity development continues to be prioritized in the Sorghum and Millet Innovation Lab as it moves into its second phase of research activities. Long-term trainees from the first phase are completing their degrees and are contributing to research community as they establish their own programs. New long-term trainees are being added to the ranks with the launch of new and renewed projects, while short-term trainings continue even in the midst of the transition between phases. The Lab maintains its focus on the development of institutions and capacity – particularly among NARS – to set their own priorities and drive solutions.

Short-term training

FY 2019 was a year of transition between research activity phases for the Sorghum and Millet Innovation Lab, so the overall number of short-term trainings was lower than in previous years. In FY 2019, the Lab facilitated the short-term training of nearly 390 individuals across 14 different training events. The types of short-term trainings conducted varied, and included farmer trainings, professional workshops, on-the-job capacity-building exercises and academic courses.

Of the 386 trainees, producers made up the largest group with 249 trained, followed by 44 civil society members (predominantly researchers and students), 28 people in private sector firms, 27 people in government and 38 unknown. Of the total trainees, 192 were female and 194 were male, demonstrating a concerted effort to target women in the training process and achieve better gender equity.

Table 1. Short-term trainees supported by the Sorghum and Millet Innovation Lab – FY 2019

Country of Training	Purpose of Training	Who was trained	Number trained		
			M	F	Total
Ethiopia	One week practical training on sorghum based food processing and quality evaluation	Government: 2 Private Sector: 7 Civil Society: 9	14	4	18
Ethiopia	1-Day Practical Training Course on Sorghum and Sorghum Malting and Brewing	Private Sector: 17	9	8	17
Ethiopia	Genomic approaches in crop improvement	Civil Society: 35	33	2	35
Ethiopia	Genomics in crop improvement	Civil Society: 20	17	3	20
Niger	Training on cereal-legume fortification using natural rich mineral & Vitamin A and testing of Digital Application	Producers: 84 Government: 9 Private Sector: 1 Civil Society: 1	24	71	95

Niger	Training/certification on "innovation know how" to new women rural processor groups	Producers: 47 Government: 5 Private Sector: 1 Civil Society: 1	5	49	54
Niger	Sélection des variétés à double usage en parcelle paysanne	Producers: 76 Government: 4 Civil Society: 1	56	24	81
Niger	Technique of hybrid seed production	Producers: 2 Government: 1 Private Sector: 2 Civil Society: 5	7	3	10
Niger	Student training on field research best practices	Civil Society: 6	5	1	6
Niger	Hands-on training for drought phenotyping and methodologies to screen genotypes for drought tolerance	Civil Society: 1	1	0	1
Senegal	Three millet farmer participative field days with during sowing, at maturity and at evaluation time	Producers: 40 Government: 4	20	24	44
Uganda	Gender-Responsive in plant breeding/GREAT	Government: 2	2	0	2
Uganda	Gender-Responsive in plant breeding/GREAT	Government: 2	2	0	2
U.S.	Training in the sorghum Practical Haplotype Graph	Civil Society: 1	1	0	1

Long-term training

In FY 2019, the Sorghum and Millet Innovation Lab saw a number of long-term training programs come to a close as Phase 1 of the research activities were wrapped up. There were a total of 68 long-term trainees in the first phase, with a small number that will complete their programs in the early part of Phase 2.

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 2019 (Phase 1)

Trainee number	Sex	University	Degree	Major	Graduation date	Degree granted?	Home Country
1	Male	Universite Prive de Segou Agri SUP	Bachelor's	Agronomy	Dec-18	Yes	Mali
2	Male	INRAN	Bachelor's	Agronomy	Nov-17	Yes	Niger
3	Female	CERAAS	Bachelor's	Agronomy	Jan-17	Yes	Niger
4	Male	ICRISAT – Niger	Bachelor's	Ecophysiology	Dec-18	Yes	Niger
5	Female	CERAAS	Bachelor's	Agronomy	Jan-17	Yes – Pursuing Master's degree at University Cheikh Anta Diop	Senegal
6	Male	ISFAR/University of Thies	Engineer	Agricultural Engineering	Jul-17	Yes – on an internship with an agricultural entreprise	Senegal
7	Female	ISFAR/University of Thies	Engineer	Agricultural Engineering	Jul-16	Yes – has been recruited by agricultural firm, SODAGRI	Senegal
8	Male	University of Ouagadougou	Master's	Breeding and conservation of seed	Apr-17	Yes	Burkina Faso
9	Female	INERA	Master's	Seed selection and conservation (SELCOSE)	Dec-15	Bachelor's granted, now working on Master's	Burkina Faso
10	Male	Hawassa University	Master's	Food science and postharvest technology	Dec-18	Yes	Ethiopia
11	Female	Haramaya University	Master's	Plant pathology/breeding	May-18	Yes	Ethiopia
12	Male	Haramaya University	Master's	Plant pathology/breeding	Oct-17	Yes	Ethiopia
13	Male	Kansas State University	Master's	Agricultural Economics	May-18	Yes - now pursuing Ph.D. at Kansas State University	Ethiopia
14	Male	CHIBAS	Master's	Genetics	Nov-17	Yes	Haiti
15	Male	INRAN	Master's	Socio-economy	Jan-18	Yes	Niger
16	Male	Université Abdou Moumouni de Niamey	Master's	Entomology	Jan-18	Yes	Niger
17	Male	Universite Dan Dicko Dankoulodo	Master's	Agronomy	Dec-17	Yes	Niger
18	Male	Université Abdou Moumouni de Niamey	Master's	Entomology	Jan-18	Yes	Niger
19	Male	University of Tahoua	Master's	Socio-economy	Dec-17	Yes	Niger
20	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
21	Male	ENSA Thies	Master's	Socio-economy	Dec-17	Yes	Senegal
22	Female	ITA	Master's	Agricultural Economics	May-16	Yes	Senegal

23	Male	CERAAS	Master's	Microbial and vegetal biotechnology	Sep-17	Yes	Senegal
24	Male	University Cheikh Anta Diop	Master's	Pest Management	May-17	Yes – on an internship with AGRA; looking for Ph.D. funding	Senegal
25	Female	ENSA/University of Thies	Master's	Sustainable development and society/agriculture	Aug-17	Yes – searching for Ph.D. funding	Senegal
26	Male	University of Thies	Master's	Agricultural engineering	Apr-17	Yes	Senegal
27	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
28	Male	CERAAS	Master's	Breeding	Apr-16	Yes – currently applying to DADD fellowship program for Ph.D.	Côte d'Ivoire
29	Male	Haramaya University	Master's	Plant pathology/breeding	Dec-15	Yes – works for BAKO Research Center at Oromia Research Institute	Ethiopia
30	Female	Hawassa University	Master's	Food Processing and Preservation	Mar-17	Yes – now employed at a private company	Ethiopia
31	Male	Haramaya University	Master's	Agronomy	Jul-16	Yes - now working for Oromia Agricultural Research Institute, Fedis Research Center	Ethiopia
32	Female	Abdou Moumouni University of Niamey with Short Training at Virginia Tech	Master's	Agricultural Economics	Jan-18	Yes	Niger
33	Female	University Cheikh Anta Diop	Master's	Pest management	Dec-15	Yes – recruited by agricultural entreprise	Senegal
34	Male	ISRA	Master's	Agroforestry ecology and adaptation	Nov-18	Yes	Senegal
35	Female	ISRA	Master's	Analytical Chemistry	Jul-18	Yes - under consideration for a Ph.D., in training at biochemistry lab at CERAAS	Senegal
36	Male	Virginia Tech	Master's	Agricultural Economics	May-16	Yes – works (volunteers) for U.S. Peace Corps in the Philippines	United States
37	Male	Kansas State University	Ph.D.	Agricultural Economics	Jul-18	Yes - working at the FAO	Burkina Faso
38	Male	Purdue University	Ph.D.	Plant breeding and genetics	1-May-19	Yes	China
39	Male	Purdue University	Ph.D.	Plant pathology	May-20	No	Ethiopia
40	Male	Kansas State University	Ph.D.	Plant breeding and genetics	Dec-19	No	Ethiopia
41	Male	Kansas State University	Ph.D.	Plant pathology/breeding	Dec-20	No	Ethiopia
42	Female	Purdue University	Ph.D.	Food science	Aug-18	Yes - working as a post-doc at North Carolina State University	Ethiopia
43	Male	University of Pretoria	Ph.D.	Food Science	Jul-18	Yes - working at Hawassa University	Ethiopia
44	Male	Purdue University	Ph.D.	Plant breeding and pathology	Dec-20	No	Ethiopia
45	Male	Texas A&M	Ph.D.	Food Science	Dec-18	Yes - working at Hawassa University	Ethiopia

46	Female	Purdue University	Ph.D.	Agronomy	Dec-18	Yes	Germany
47	Male	University of Maradi	Ph.D.	Entomology	Dec-19	No	Niger
48	Male	West Texas A&M University	Ph.D.	Plant, Soil and Environmental Science - Insect Pest Management	May-19	Yes - working at INRAN	Niger
49	Male	ICRISAT – Niger	Ph.D.	Entomology	Dec-19	No	Niger
50	Female	Kansas State University	Ph.D.	Agronomy (Plant Breeding & Genetics)	May-20	No	Niger
51	Male	INRAN	Ph.D.	Food Science	Dec-19	No	Niger
52	Male	West African Center for Crop Improvement	Ph.D.	Plant Breeding	May-19	Yes - working at INRAN	Niger
53	Female	INRAN	Ph.D.	Agronomy/Soil science	Feb-19	Yes	Niger
54	Male	University of Hohenheim	Ph.D.	Agriculture	Jun-17	Yes - working as post-doc at University of Hohenheim	Nigeria
55	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
56	Male	CERAAS	Ph.D.	Plant breeding and genetics	Dec-19	Yes - working at CERAAS	Senegal
57	Female	West African Center for Crop Improvement	Ph.D.	Plant Breeding	Jul-19	Yes - working for ISRA/CERAAS on Sorghum Trait Development Pipeline	Senegal
58	Male	Cheikh Anta Diop University/ITA	Ph.D.	Microbiology	Apr-19	No	Senegal
59	Female	Cheikh Anta Diop University	Ph.D.	Food Science and Nutrition	Jul-18	Yes	Senegal
60	Male	Kansas State University	Ph.D.	Agronomy (Plant Breeding & Genetics)	May-20	No	Senegal
61	Female	University Cheikh Anta Diop	Ph.D.	Entomology	Dec-17	Yes	Senegal
62	Female	University of Thies	Ph.D.	Pest management	Dec-17	Yes	Senegal
63	Female	University Cheikh Anta Diop	Ph.D.	Pest management	Dec-17	Yes	Senegal
64	Male	CERAAS	Ph.D.	Agronomy (Breeding & Genetics)	Jan-18	Yes - working at ITRA in Togo	Togo
65	Male	Purdue University	Ph.D.	Plant Genetics	May-16	Yes – works at Makerere University in Uganda	Uganda
66	Female	Purdue University	Ph.D.	Food Science and Nutrition	Aug-19	Yes	USA
67	Female	Cornell University	Ph.D.	Plant breeding and genetics	Aug-21	No	USA
68	Male	Purdue University	Post-doctoral Studies	Plant Genetics	Jun-17	Yes	Nigeria

A small number of long-term trainees began their training programs with the launch of Phase 2 earlier in FY 2019. The Lab expects more trainees in the coming year as the new research projects begin in earnest.

Table 3. Long term trainees supported by the Sorghum and Millet Innovation Lab – FY 2019 (Phase 2)

Trainee number	Sex	University	Degree	Major	Graduation date	Degree granted?	Home Country
69	Male	University of Tillaberi	Master's	Plant Pathology/Plant Breeding	May-21	No	Niger
70	Male	Universite Abdou Moumouni Niamey	Master's	Crop Physiology	Mar-20	No	Niger
71	Male	Universite Abdou Moumouni Niamey	Master's	Crop Physiology	Dec-19	No	Niger

Institutional development

As the Sorghum and Millet Innovation Lab proceeds into its second phase of activities, it continues to identify opportunities and mechanisms by which to strengthen the institutional capacity of its partners and national research systems. One of the ways that it does this by ensuring that its own systems and processes reinforce those of the international partner institutions that it works with. One example of this has been the Lab's approach to in-country coordination in Ethiopia. In past years, a single in-country coordinator has been selected to serve in a role of oversight of research activities as well as a Lab representative at broader research and food security events and activities. However, the Ethiopian Institute of Agricultural Research (EIAR) expressed the desire for a new approach that assigns individual researchers as coordinating "co-PIs" to each project. In order to reinforce EIAR's systems for maximum alignment, the Lab implemented this change of its own coordination approach to match that of their in-country partners.

In addition, the Lab has been contacted on multiple occasions by groups and organizations (including NGOs and donor organizations) interested in partnering or collaborating on potential initiatives in the Lab's focus countries. On numerous instances, the Lab has served as moderator between those organizations and in-country partners that are best aligned to collaborate with the initiating organization. By serving in this role, the Lab has been successful in assisting in the establishment of relationships between key players while empowering in-country partners to take key leadership roles in collaborative initiatives, which has, in turn, expanded their networks and grown their capacity and competency in serving as direct partners to internationally-led development initiatives.

Innovation transfer and scaling partnerships

Technology transfer and scaling is the clear long-term objective for the Sorghum and Millet Innovation Lab in regards to all technologies that are successfully developed through the various phases of research, field testing and initial dissemination. With the implementation of the USAID Research Rack Up in 2018, the Lab has made efforts to ensure that reporting of technological innovation development remains consistent across all platforms. As a result, it has modified its reporting approach in this report to match that of the Research Rack Up.

In past years, all technological innovation efforts were reported as technologies under development, with most being listed as Phase 1 (Under Research). However, many of these were still at a highly conceptual level that lacked specific detail or descriptor and therefore were not yet at the level of development to be appropriate for the Research Rack Up. In order to remain consistent with those technologies that the Lab feels are appropriate and applicable to be reported in the Rack Up, this report will highlight only those technological innovations that are in a defined stage of development and have been reported to the Rack Up.

Phase 3 technologies (Made available for transfer)

Technologies 1-3 were previously reported into the Rack up in FY 2018; technologies 4-5 were first reported in FY 2019.

1. 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

2. 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

3. *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

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

Category: Management practices

Area of inquiry: Production systems management

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

FY 2019 progress made: The seedball technology is physically and chemically optimized for hand production and ready for dissemination. A technical sheet was provided.

Next steps: Field testing in 2017/18 has shown that the technology works using materials from different locations and independently from other factors like soils or gender. Now the technology needs to be tested under real world conditions, i.e. applying other yield enhancing management techniques that are usually applied by farmers and distributed to other Sahelian areas, where applicable.

Target countries: Senegal and Niger

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

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

Phase 2 technologies (Under Field Testing)

1. Technology: Seedball fabrication mechanisation 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

FY 2019 progress made: A mechanical option was developed and tested but failed to be time-efficient, i.e. the seedball product was standardized but the mechanical tool did not reduce workload.

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 country: Niger

2. Technology: Seedball fabrication mechanisation 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

FY 2019 progress made: A mechanical option was provided but failed to be time-efficient. The seedball product was standardized but workload was not significantly lower.

Next steps: The mechanisation option has shown to work under farmers' condition. However, local craftsmen were not able to copy it. So modifications need to be developed with craftsmen and farmers together, also in order to increase productivity. The presented tool did not sufficiently reduce working time needed in comparison to hand-made seedballs.

Target country: Niger

3. *Pre-release of two new high yielding multipurpose Melanaphis resistant varieties for Haiti*

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: Prof Patrice Dion, Département de phytologie – IBIS, Université Laval - Canada

National Seed System, Ministry of Agriculture, Natural Resources and Rural Development - Haiti

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

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: Purdue University, 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

Environmental Management and Mitigation Plan (EMMP)

The Sorghum and Millet Innovation Lab management entity has continued to ensure environmental compliance and confirm 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. Fertilizer commodity purchases were applied for and approved by USAID for research plot activities.

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.

Open data management plan

During FY 2019, the Sorghum and Millet Innovation Lab has made considerable progress in ensuring compliance by all projects and research teams with USAID open data policy. All Phase I projects were required to submit a project-level data management plan for all datasets produced during the first phase. These submissions were made via the SMIL Resource and Reporting Hub on Piestar. A subsequent program-level open data management plan was produced and provided to USAID. All projects were then required to submit all data sets not currently under embargo restrictions to the Developmental Data Library (DDL). The Lab will continue to monitor data set reporting by projects to ensure compliance around all applicable data.

An updated data management plan will be drafted in FY 2020 to incorporate the anticipated data sets that will be produced under new and continued research activities in Phase 2.

Governance and management entity activity

Phase I close down and Phase 2 project launch

FY 2019 was focused heavily on the transition between phase I research projects and activities and new phase 2 priorities. Most phase I projects had received a no-cost extension through mid-2019 in order to complete final research activities or wrap up student training, so this fiscal year was spent bringing those projects to a close, both operationally and administratively.

Additionally, project launch and phase 2 startup was also completed in full during this fiscal year. Successful phase I projects were evaluated by the Lab's external advisory board and management entity and considered for continuation into new phase 2 projects to further expand on discoveries from the first phase. Additional research needs were identified in the areas of pearl millet value chain research and sorghum pathology in West Africa, and calls for proposals were issued in order to address these needs. As a result, two new projects were developed and launched for the second phase of the program.

Technology Scaling – Showcase Meeting

Scaling technology packages continue to be a key program deliverable for the Sorghum and Millet Innovation Lab. There are multiple "ingredients " that support scaling including technology practice, awareness/demand, business case, value chain integration, finance, knowledge/skills, collaboration networks, evidence/learning level, leadership/management, and public sector governance. In an effort to build awareness/demand and strengthen collaboration networks, the Lab organized a half-day technology showcase meeting in Niger in partnership with the USAID mission in April 2019. This showcase demonstrated those Lab-supported technologies currently ready and available for scaling to a wider network of development partners who were invited by the USAID Niger mission to participate.

Other Topics

Gender roles in sorghum production, processing and utilization in Ethiopia

During its first five-year phase, the Sorghum and Millet Innovation Lab commissioned a gender study to assess gender roles and sorghum production/utilization by region in Ethiopia. The regional multi-disciplinary 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. This fiscal year saw the final steps completed in the drafting and editing of those reports, which were then made available for public access on the Lab's website as well through broader communications.

Communications – Technology catalog

As previously noted, the Lab places high priority on linking other research and development partners to the technologies that have been developed and improved as a part of Lab-funded activities. One way is has chosen to do this is by developing a "technology catalog" on the Sorghum and Millet Innovation Lab website. On the technology catalog page, each Lab-developed technology that is ready for dissemination and scaling is listed along with the following details:

- Crop
- Target country
- In-country contact
- Principal investigator
- Description
- Additional resources (such as videos or fact sheets)

This catalog will continue to be updated with the most current information and as new technologies are readied for scaling. It is hoped that by making these technology descriptions available to the public, they will become more accessible to the development community and will be applied more widely to help address key challenges.

Future directions

The Sorghum and Millet Innovation Lab is entering into a mature state with numerous scientific initiatives in genetic enhancement, production systems management and value-added food products. Each of these initiatives is generating new technologies for end-users in several different domains including farmers, food processors, the private sector and the global research community. The research community is benefiting from global public goods generated in the area of understanding plant genetics, genomic-enabled breeding processes, and the discovery of loci in the sorghum genome conferring resistance against anthracnose and the sugarcane aphid. These advances will be harnessed and integrated into building more resilient crop varieties for the future and investment will continue to support these initiatives.

Downstream activities will concentrate on extending technologies that have evolved to the scaling phase in collaboration with several development organizations. Several avenues have been identified including collaborative efforts with national development programs supported by bilateral funding, new initiatives with the World Food Program, private sector firms in agricultural input and food product supply in both West Africa and Ethiopia.

The program is supporting fewer long-term trainees during this phase and is focusing efforts and supporting new graduates as the start their careers in-country. Innovative programs of mentorship between senior researchers and junior researchers have been developed for professional growth and development and also to reinforce research networks. These mentorship platforms serve to generate greater resiliency in regional and national research ecosystems so that areas of expertise can grow, specialize further and feel confident that when a key scientist retires, another is ready to carry forward the research area.

The program will continue to collaborate with regional initiatives in West Africa supported by other donors in a manner that is consistent with the objectives of CORAF and its constituents. In Ethiopia, we seek to empower the Ethiopian National Sorghum Program to chart its own future and priorities as the program continues on its mission to increase national food security.

Appendices

Appendix 1 – Success stories

NIGERIEN FOOD SCIENTIST TACKLES FOOD AND INCOME SECURTY THROUGH FOOD PRODUCT DEVELOPMENT

Income security and improved nutrition are two key priorities for households and families across the Sahel, where lack of employment opportunities and food insecurity are alarmingly widespread. Countless governments, NGOs and entrepreneurs are all working to address these challenges from numerous angles, but one individual has dedicated his career to building opportunities and enhancing market access for women entrepreneurs.

Moustapha Moussa, a Nigerien food research scientist in the Food Processing Lab at the Institut National de Recherche Agronomique du Niger (INRAN), recently completed his Ph.D. at Purdue University as a part of his broader research activities with the Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet. His research in food science was focused on the development of new food processing technologies to support urban and rural entrepreneur food processors and to expand nutritious foods through the marketplace.

Moussa has spent more than 15 years working in grain chemistry and processing to develop competitive and nutritious value-added goods in West Africa. He most frequently works with women entrepreneurs in the region, helping to provide income generation opportunities through new food product and business development. He hope that by achieving a Ph.D., he will return with an even greater number of tools to advance his past efforts in food and income security.

"To me, this Ph.D. degree will greatly advance my professional objectives by providing me with the technical skills and leadership capabilities to properly contribute to the strengthening of institutional capacity," Moussa says. "I hope it will allow me to grow international collaboration for innovation, development and technology transfer on grain foods to improve food security, nutrition, health of the local community and economic growth in Niger and West Africa."

Upon return to Niger, Moussa will continue to expand his activities at INRAN in relation to technology development in partnership with the Sorghum and Millet Innovation Lab and the McKnight Foundation, among other international organizations. He will employ a "hub-and-spoke" food innovation center model to further scale the processing technologies and entrepreneurial concepts developed to address key nutritional and income needs.

"From his Ph.D. research, Moustapha brings broader knowledge and skills on how to advance food processing in Niger and the region, and specifically through incubation of women processors, whether urban entrepreneurs or rural women's associations," says Dr. Bruce Hamaker, professor of food science at Purdue University and Moussa's major advisor and research colleague. "He gained an expanded understanding of nutrition science and the essentials of formulating nutritionally-enhanced foods for children and youth, and his team will put more focus on getting nutrient-fortified foods using locally sourced natural fortificants into low-cost processed products that could impact nutritional status of vulnerable groups."

After years of hard work and study, Moussa is ready to further apply his knowledge and experience towards improving food and income security and bettering the lives of millions of Nigeriens.

Dr. Moustapha Moussa presents a food processor and entrepreneur with a certificate of completion for a processing training course in Niger. (Credit: Moustapha Moussa)

DRIVING CROP IMPROVEMENT THROUGH INTERNATIONAL COLLABORATION

The sugarcane aphid is a destructive sorghum pest found worldwide that began progressively expanding its range across North America in 2013. Its impact has been seen in nearly all major sorghum-producing areas, and it has caused crop devastation for countless sorghum producers.

In the Caribbean, Haitian farmers have also felt the shock of the sugarcane aphid's sweep through the Americas. As one of the world's poorest and most densely populated countries, the losses resulting from sugarcane aphid infestations have only worsened an already fragile economy that suffers from high levels of poverty, natural disasters and political instability. For those farmers and families that depend on sorghum for their livelihoods and nutrition, the sugarcane aphid represents a deep threat to their health and futures.

The best defense against the sugarcane aphid is resistant sorghum lines, but breeding for resistance is typically a slow and painstaking process. Thanks to an innovative new breeding program, sixty years of international research cooperation, and bit of good luck, Haiti's sorghum producers already have solutions arriving in their fields.

Breeders from around the world have been working together on sugarcane aphid resistance for decades, long before the pest made it to North American and Caribbean sorghum fields. Investment by the United States Agency for International Development (USAID) under the International Sorghum and Millet Collaborative Research Support (INTSORMIL) program had supported substantial amounts of germplasm exchange across all sorghum-producing regions. It was in the lines introduced from Africa that breeders first identified sugarcane aphid resistance.

With the recent rise of the sugarcane aphid, researchers and breeders began looking harder at the sorghum lines developed years prior, resulting in new sugarcane resistant breeding lines released in 2018 in the U.S. by Texas A&M University under the Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet (SMIL), the successor program to INTSORMIL.

While the U.S. sorghum industry was responding to the sugarcane aphid crisis, Haiti was reeling from its own aphid infestation. Haiti's sorghum breeding program, led by Dr. Gael Pressoir at CHIBAS and Université Quisqueya had to respond. Pressoir had recently launched a new program based on diverse global sorghum and luckily, the new breeding program harbored a rare aphid resistance gene. While almost all traditional and improved varieties were wiped out by the aphid, a few breeding lines were left standing. These aphid resistant lines would serve as the foundation of efforts by Pressoir and international collaborators to develop new locally-adapted varieties for Haitian farmers. The result was the pre-release of two high-yielding, multipurpose sorghum varieties that carry sugarcane resistance, with full release to farmers throughout Haiti planned for the end of 2019.

Pressoir, along with collaborators Dr. Ed Buckler from Cornell University and Dr. Geoffrey Morris of Kansas State University, had already partnered on a USAID award from the SMIL program on genomics-assisted breeding in Haiti.

"Our genomic analysis revealed that sorghum in Haiti was only saved because of sixty years of global germplasm exchange – spanning Ethiopia, United States, India, Senegal, Burkina Faso, and Haiti," says Dr. Morris, associate professor of sorghum genetics at Kansas State University. "Our research proves that global sharing of crop diversity and technology safeguards agriculture in developing countries – and here in the U.S. – against severe and unexpected threats."

Genomic research also delivered new aphid-fighting genetic marker technology, now being deployed by breeders in both Haiti and the U.S. Genomic analysis by SMIL researcher Kebede Muleta, a postdoc in the Morris lab, had revealed the precise genome region that provided aphid resistance in Haiti. The same genome region was independently identified by researchers studying sorghum in China. Based on these findings, Muleta's coworker and Kansas State University molecular breeder Terry Felderhoff, developed genetic markers that are now being used to breed new aphid-resistant varieties in Haiti and the U.S. This technology further accelerates the global effort to combat sugarcane aphid and

safeguard livelihoods that depend on sorghum. Researchers expect that within a few years, sorghum farmers in Haiti and the U.S. will be growing aphid-resistance varieties made possible by cooperation across Africa, Asia, and the Americas, and USAID support of global collaboration.

Sorghum breeder Gael Pressoir and farmer-outreach worker discuss the challenges of sorghum production in Haiti (Credit: Geoffrey Morris)

BETTER SORGHUM FOR BETTER FOOD PRODUCTS

Due to increased disposable income and the rise of the middle class, more and more families in Ethiopia are purchasing their injera – a fermented, pancake-like flatbread that is a staple part of daily diets - from local vendors instead of preparing it at home. Injera has traditionally been prepared most commonly from teff, a small grain that is grown widely in Ethiopia. However, in some regions – particularly rural areas - sorghum is used for injera making in place of teff thanks to sorghum's availability and affordability (half the price of teff). Yet, due to its physio-chemical traits, sorghum tends to underperform in the making of injera, which limits its use as a base ingredient and keeps the price of injera higher with the dependence on teff.

In an effort to improve the functionality of sorghum in commercial grain-based food products such as injera and pan breads and provide individuals and processors alternative ingredient options, improved highly-digestible (IHD) sorghum lines have been developed at Texas A&M University in the U.S. These lines combine a high protein digestibility mutation with waxy and heterowaxy starch traits in hard endosperm to form a sorghum grain that shows considerable promise for various food applications due to its superior functionality and improved protein nutritional quality.

Under funding from the Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet, food scientists from Texas A&M University and Hawassa University in Ethiopia have worked with food product development labs and local entrepreneurs to assess the performance of the IHD sorghum lines and have confirmed that they display improved performance in food processing. Consumer preference studies show that injera made from blends with these improved sorghum lines performs as well as 100% teff injera and is equally preferred, evidence of the strong potential of the new varieties.

While the improved sorghums perform well in the food product development lab, they must also perform equally well in the fields in order to offer a practical alternative for farmers and their families who depend on sorghum for their livelihoods. Researchers are currently testing these IHD lines in Ethiopian environments in order to evaluate production constraints and opportunities for local farmers. Initial results are showing strong performance in the field and the research team anticipates establishing a hybrid seed and grain production system for the improved lines in the coming years in order to make them widely available for the country's food processing industry.

"Success in this research will lead to development of commercially-viable, superior-quality sorghum-based food products that will open new markets and enhance the sorghum value-chain in Ethiopia," says Dr. Joseph Awika, principal investigator and professor of food science and nutrition at Texas A&M University. "We expect that the improved sorghum hybrids can be successfully incorporated into the mainstream food processing value chain to produce commercially competitive products that meet quality expectations of a broad consumer base in Ethiopia. We also expect that the improved sorghum hybrids will compete favorably with local hybrids in both high input and low input environments in Ethiopia."

According to Awika, the benefits of the incorporation of the improved, higher-quality lines have the potential of broader impact – both economically as well as nutritionally.

"This initiative will benefit small-scale farmers who dominate sorghum production as well as small- and medium-scale food enterprises, a large portion of which are female-owned," he says. "Additionally, increased utilization of these improved sorghums in local products would significantly contribute to reduced malnutrition in children from regions that rely on sorghum as a staple."

New improved highly-digestible (IHD) sorghum lines have shown high performance in the food products lab are now under evaluation in Ethiopian growing conditions. (Credit: Joseph Awika)

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

** One year no-cost extension was granted*
*** Two year no-cost extension was granted*

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 07/22/19*

FY19 Funding Released:	$0.00
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 07/22/19*

FY19 Funding Released:	$0.00
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 07/22/19*

FY19 Funding Released:	$0.00
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 07/22/19*

FY19 Funding Released:	$0.00
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 07/22/19*

	Purdue	KSU	Total
FY19 Funding Released:	$22,145.00	$0.00	$22,145.00
Total Funding Released:	$753,438.00	$188,924.00	$942,362.00
Overall Project Budget:	$753,438.00	$188,924.00	$942,362.00

Title: Development of Biotic Stress-Resistant Sorghum cultivars for Niger and Senegal
Award: WTAMU - Bonnie Pendleton
Project Dates: 04/01/14 07/22/19*

FY19 Funding Released:	$0.00
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 07/22/19*

	KSU	USDA	Total
FY19 Funding Released:	$0.00	$0.00	$0.00
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 07/22/19*

FY19 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 07/22/19*

FY19 Funding Released:	$0.00
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 07/22/19*

FY19 Funding Released:	$0.00
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 09/30/21**

FY19 Funding Released:	$170,763.00
Total Funding Released:	$410,796.00
Overall Project Budget:	$582,127.00

Title: Implement a genomics-assisted breeding program in a small breeding program in a developing country
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 – List of awards to U.S. partners – Phase II

Title: Advancing improved functionality and protein quality sorghum hybrids for food applications in Ethiopia
Award: Texas A&M - Joseph Awika
Project Dates: 04/01/19 07/21/23

FY19 Funding Released:	$129,419.00
Total Funding Released:	$129,419.00
Overall Project Budget:	$929,658.00

Title: Genetic Enhancement of Sorghum to Promote Commercial Seed Supply and Grain Market Development in Ethiopia
Award: Purdue - Gebisa Ejeta
Project Dates: 04/01/19 07/21/23

FY19 Funding Released:	$109,255.00
Total Funding Released:	$109,255.00
Overall Project Budget:	$472,500.00

Title: Expanding Markets for Sorghum and Millet Farmers in West Africa through Strengthening of Women and Youth Processors and Nutrition-based Promotion of Products
Award: Purdue - Bruce Hamaker
Project Dates: 04/01/19 07/21/23

FY19 Funding Released:	$97,125.00
Total Funding Released:	$97,125.00
Overall Project Budget:	$523,567.00

Title: Phase II - Genetic improvement of sorghum for resistance to fungal pathogens
Award: Purdue - Tesfaye Mengiste
Project Dates: 04/01/19 07/21/23

FY19 Funding Released:	$118,741.00
Total Funding Released:	$118,741.00
Overall Project Budget:	$814,897.00

Title:	Enabling Marker Assisted Selection for Sorghum Disease Resistance in Senegal and Niger	
Award:	TAMU – Clint Magill	
Project Dates:	04/01/19	07/21/23

FY19 Funding Released:	$8,910.00
Total Funding Released:	$8,910.00
Overall Project Budget:	$384,645.00

Title:	Sorghum Trait Deployment Pipeline for Improved Food and Feed Value	
Award:	Purdue - Mitch Tuinstra	
Project Dates:	04/01/19	07/21/23

FY19 Funding Released:	$23,031.00
Total Funding Released:	$23,031.00
Overall Project Budget:	$155,991.00

Title:	SAWAGEN: Improving Sorghum Adaptation in West Africa with a Genomics-Enabled Breeding Network	
Award:	KSU - Geoff Morris	
Project Dates:	04/01/19	07/21/23

FY19 Funding Released:	$86,250.00
Total Funding Released:	$86,250.00
Overall Project Budget:	$426,066.00

Title:	Genetic Enhancement of Pearl Millet for Yield, Biotic and Abiotic Stress Tolerance in West Africa (GENMIL)	
Award:	KSU-Hays - Desalegn Serba	
Project Dates:	04/01/19	07/21/23

FY19 Funding Released:	$26,758.00
Total Funding Released:	$26,758.00
Overall Project Budget:	$171,515.00

Appendix 4 – Country-specific financial information

Phase I Funds received per Country	
Country	Total
Niger	$ 1,343,057.00
Senegal	$ 962,062.00
Ethiopia	$ 905,990.00
Mali	$ 152,664.00
Ghana	$ 210,000.00
Burkina Faso	$ 128,665.00
South Africa	$ 258,526.00
Germany	$ 61,936.00
GRAND TOTAL	**$ 4,022,900.00**

Phase II Funds received per Country	
Country	Total
Niger	$ 195,500.00
Senegal	$ 182,000.00
Ethiopia	$ 50,000.00
Burkina Faso	$ 32,000.00
Togo	$ 30,000.00
Germany	$ 56,756.00
GRAND TOTAL	**$ 546,256.00**