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 2021

*October 1, 2020 – September 30, 2021*

USAID FROM THE AMERICAN PEOPLE

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 2021

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**Cover photo:**
Participants in a Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet (SMIL) Annual Review Meeting held in Niamey, Niger
Photo credit: Kira Everhart-Valentin

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## Management Entity Information

The management entity completed the fiscal year 2021 with the following staff members:

- Timothy J. Dalton, Ph.D. – *Director*
- Nathanael D. Bascom – *Assistant Director*
- Benjamin E. Kohl, Ph.D. – *Program Administrator*
- Kimberly A. Suther – *Fiscal Analyst*

## External Advisory Board Information

Since the inception of the Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet (SMIL), the External Advisory Board (EAB) has played a key role in ensuring that SMIL's research and management practices are both high-quality as well as relevant. The EAB members have remained consistent throughout the life of SMIL. All original five members elected to continue their service into Phase 2, and are joined by our USAID Agreement Officer Representative, Dr. Faith B. Tarr.

1) Dr. Faith B. Tarr – *Agreement Officer Representative (AOR) at USAID*
2) Dr. Brhane Gebrekidan - *Ethiopian Academy of Sciences*
3) 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*
4) Mr. Timothy Lust - *Chief Executive Officer of the National Sorghum Producers*
5) Dr. Peter Matlon - *Adjunct Professor at Cornell University*
6) Prof. Barbara Stoecker - *Regents Professor and Marilynn Thomas Chair at Oklahoma State University*

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.

Our face-to-face annual meeting was moved to an online version due to the COVID-19 pandemic. The External Advisory Board (EAB) provided valuable input to each project's representatives. The EAB found the format to be effective way to discuss each project as we reviewed them one at a time. It also allowed for more in-depth discussion and reflections.

# Focus Countries

SMIL continues to work primarily in its focus countries – Ethiopia, Senegal, and Niger – and secondarily in Burkina Faso, Togo, and Haiti, seen in Figure 1.


*Figure 1 Sorghum and Millet Innovation Lab (SMIL) map of program activities and partners*

# List of Program Partners

**United States of America**

Colorado State University
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

**Ethiopia**

Amhara Agricultural Research Institute
Asosa Agricultural Research Center
Ethiopian Institute of Agricultural Research (EIAR)
Haramaya University
Hawassa University
National Agricultural Biotechnology Research Center
Mek'ele Agricultural Research Center
Oromia Agricultural Research Institute
SNNPR Bureau of Agriculture and Natural Resources Development
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)
Mooriben (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

**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)

# Acronyms

| | |
|---|---|
| ARS | Agricultural Research Service |
| AOR | Agreement Officer Representative |
| 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 |
| COVID-19 | Coronavirus Disease of 2019 |
| CSU | Colorado State University |
| EAB | External Advisory Board |
| ECC | Ethiopian Core Collection |
| EIAR | Ethiopian Institute of Agricultural Research |
| EMMP | Environmental Mitigation and Monitoring Planning |
| EMS | Ethyl Methanesulfonate |
| DNA | Deoxyribonucleic Acid |
| GBS | Genotyping-by-sequencing |
| GENMIL | Genetic Enhancement of pearl Millet |
| GoHy | Goal-Directed Hypothesis-Driven |
| GWAS | Genomic-wide Association Study |
| 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 |
| 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 Institute(s) |
| NARS | National Agricultural Research System(s) |
| NSP | National Sorghum Producer(s) |
| OPV | Organic photovoltaic |
| OSU | Oklahoma State University |
| PI | Principal Investigator |
| PMP | Performance Monitoring Plan |
| QTL | Quantitative Trait Locus |
| R&D | Research and Development |
| R4D | Research for Development |
| RFA | Request for Application |

| | |
|---|---|
| SAWAGEN | Sorghum Adaptation in West Africa with a Genomics-Enabled Breeding Network |
| SICNA | Sorghum Improvement Conference of North America |
| SME | Small Medium Enterprises |
| SMIL | Sorghum and Millet Innovation Lab |
| SNP | Single Nucleotide Polymorphism |
| UAV | Unmanned Aerial Vehicles |
| 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 |

## Glossary

Agglomerate: Process of creating food product balls, such as couscous
Anthracnose: A group of fungal diseases
Forage: Plant material consumed by livestock
Fortificant: Food additive to increase nutritional quality
Genomic enabled: Plant breeding selection process focusing on genetic markers
Genotyping: The process of determining genetic differences
Landrace: Traditional or local unimproved plant or animal
Lysimeter: A device that can measure evapotranspiration
Pathotype: A disease-causing variant of a microorganism
Phenotyping: Assessment of expressed traits in plants
Phylogeny: The evolutionary development and diversification of a species
Pleiotropic: Producing multiple effects from a gene
Smut: Fungal disease
Stover: Leaves and stalks of a plant
Striga: Genus of a parasitic plant

# Table of Contents

# Executive Summary

The Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet (SMIL) completed its eighth year during the 2021 fiscal year. This is the third year of the second phase.

Substantial progress was made on all projects and each one is moving towards downstream impact. New sorghum and pearl millet varieties have been officially released and each is in a state of seed multiplication for on-farm demonstration and end-user uptake. Agronomic interventions have been adopted by over 3,000 farmers, most of who are women, to increase production resiliency by increasing seedling stand establishment. New food products are being sold in the marketplace, nutritional interventions evaluated, and the market potential of these products has been estimated.

SMIL continues to fight for stronger production and economic resiliency through a diversified set of program activities. The program focuses on increasing sorghum and pearl millet adaptation to climate stressors through broad strategies to increase heat and drought tolerance of sorghum in Ethiopia and Haiti and both crops in West Africa. SMIL is also targeting specific biotic and abiotic stresses that rob plants of yield when subjected to disease, insects, and soil deficiencies. SMIL has identified genes responsible for host plant resistance against anthracnose, midge and grain mold and is pursuing the search for additional defensive traits to bolster production resiliency. Success with identifying anthracnose resistance in western Ethiopia has led to the release of a new sorghum variety, seed multiplication, demonstration, and distribution in dozens of locations with thousands of farmer visits. Radio programming in local dialects has raised awareness of the variety "Merera."

The seed ball program in Niger has expanded to a second cooperative in western Niger. Approximately 3,000 farmers have experimented with the seed balls, of which 90% are female. The yield advantage, calculated over four years, is often over 20% and the net return on investment is high due to the low cost of the intervention. Seed ball formulations are now being developed for sorghum and farmers ask if the technique is applicable to other crops, such as cowpea. Mechanization strategies are under development.

SMIL continues to invest in value-added food product development in both Ethiopia and West Africa. In Ethiopia, research focuses on improving the milling process for sorghum and flour refinement for evolving consumer preferences. In West Africa, the program continues to focus on urban and rural consumers and the development of fortified blends of flours, agglomerated products, and new instant food products. In collaboration with the McKnight Foundation, these products are being extended into rural areas with spillover benefits to Burkina Faso.

# Focus Country Key Accomplishments

**Ethiopia**
Strategic investments in the Ethiopian breeding program at EIAR and in regional programs are producing exciting advances to expand the frontier of sorghum profitability. Accessions from the Ethiopian Core Collection (ECC) have been released as new varieties with increased resistance against anthracnose in the western part of the country. New hybrids have been demonstrated at several locations and will be multiplied for distribution in the next year. The Ethiopian Core Collection is being used to identify new parental lines for the Ethiopian hybrid program in a move to ensure the long-run sustainability of the varietal improvement program. There were eight students from Ethiopia pursing advanced degrees during the 2021 fiscal year. The ECC also provided the basis to develop a dedicated sorghum forage variety coupled with high seeding rates for improved feed for livestock production.

**Niger**
Production resiliency of pearl millet has been enhanced with widespread testing of the seed ball technology by farmer participants in two regions of Niger. Over 3,000 farmers have tested the technology, of which over 90% are women. In addition, trials have been established to evaluate whether seed balls can improve the resiliency of sorghum and stimulate germination and establishment in the same way as pearl millet. Farmer interest has taken off and has stimulated interest in additional agronomic innovations.

The sorghum breeding program is being strengthened with the addition of new Ph.D. trained scientists to lead research on the development of two key characteristics of sorghum: highly digestible forage varieties for the livestock sector and varieties resistant against *Striga*. New inbred lines with resistance against *Striga* are being evaluated in field conditions. A large-scale survey of the prevalence and severity of sorghum diseases was completed with 21 different diseases identified. This has led to breeding strategies that incorporate identified disease-resistant cultivars with high productivity lines to increase host plant resistance and resiliency against disease outbreaks.

The added value program in Niger continues to develop improved food products for consumers and fortified blends of millet and sorghum flour for consumption by children at risk of undernourishment. Blends of these flours challenge imported soy and maize blends and are manufactured using locally available grains and micronutrient dense fortificants. Many of the products developed by INRAN under the SMIL program are being extended into rural areas of Niger and Burkina Faso through the McKnight Foundation. There were seven students from Niger pursing advanced degrees during the 2021 fiscal year.

**Senegal**
Phase-II of Sorghum Adaptation in West Africa with a Genomics-Enabled Breeding Network (SAWAGEN) sorghum project in Senegal (and associated countries) was designed with four interconnected research and development platforms, each led by an early-career NARS scientist. This approach appears to be quite successful. For instance, Cyril Diatta is developing into the regional leader of the sorghum breeding network, coordinating the development of a shared germplasm pool among the four breeding programs and providing a technical backstop for the other programs. Similarly, Jacques Faye is providing valuable quality control genotyping data for all the breeding programs, which is driving improvement of program fundamentals (record-keeping, crossing efficiency, etc.), as well as enabling marker-assisted selection. A key research goal for phase-I, which continued into phase-II, was the discovery of drought tolerance alleles in West African germplasm for use in molecular breeding of drought tolerance. Food quality sorghum is being enhanced with the introgression of genes improving protein digestibility.

The pearl millet improvement program is advancing. Over 160 farmers visited field trial plots in Senegal and identified panicle length, grain yield, stay green, and resistance to biotic stress such as *Striga*, downy mildew and drought as the most important traits when selecting a pearl millet variety to grow in their field. Based on agronomic performance and farmers' appreciation, three open-pollinated varieties (SL 169, SL 423, and SL 28) and one hybrid (TAAW) have been proposed for release.

The food product development program made significant advances in the development of an “economic” couscous that uses a non-mechanical approach to agglomerate sorghum and millet flour.  This will reduce the cost of production of the product making it more affordable for many classes of consumers. The Institut de Technologie Alimentaire in Dakar completed the development of their sensory laboratory that will develop into the region’s first center for product evaluation with trained expertise to facilitate entrepreneurial activity in the agri-foods sector. There were nine students from Senegal pursing advanced degrees during the 2021 fiscal year.

## Research Program Overview and Structure

SMIL continues 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), Colorado State University (one project), Texas A&M (two projects), the Senegalese Institute for Agricultural Research (one project) and the University of Hohenheim (one project). The pearl millet improvement project is being led by the Senegalese national agriculture research program, the Senegalese Institute for Agricultural Research (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. Activities in Haiti, under an Associate Award, have come to an end and follow-on activities were funded by SMIL's core financial resources.

The SMIL research 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, 63% of SMIL projects focus on sorghum and pearl millet crop improvement, 17% in production systems management, and 20% in added-value products. Geographically, slightly more than 35% of SMIL financial resources for research are focused on Ethiopia and the remainder in West Africa.

## Theory of Change and Impact Pathways

Figure 2 illustrates the SMIL Theory of Change (ToC). A foundational starting point are the national needs assessments that documented the demand for research by SMIL in-country stakeholders/actors. Three areas of inquiry respond to those identified research demands and the SMIL global research network has had tangible output success in technology development/deployment, as well as long-term local capacity development. The SMIL program, over time and in close collaboration with national partners, is achieving three key program goals ultimately leading to a sustainable reduction in global hunger, malnutrition, and poverty.

- *Build a coalition of science and industry around sorghum and millet.*
- *Incubate and nurture a new wave of feed and food products to stimulate demand for sorghum and millet, thereby extending economic benefits beyond the farm gate into the broader population.*
- *Create an economically rationalized business and research investment plan to leverage USAID core financing and attract associate awards and broader donor support.*

The SMIL management entity continues to facilitate diffusion of technology packages together with and our national partners through leveraging of other USAID investments and cultivating networks that support technology co-creation, dissemination, and end-user feedback.

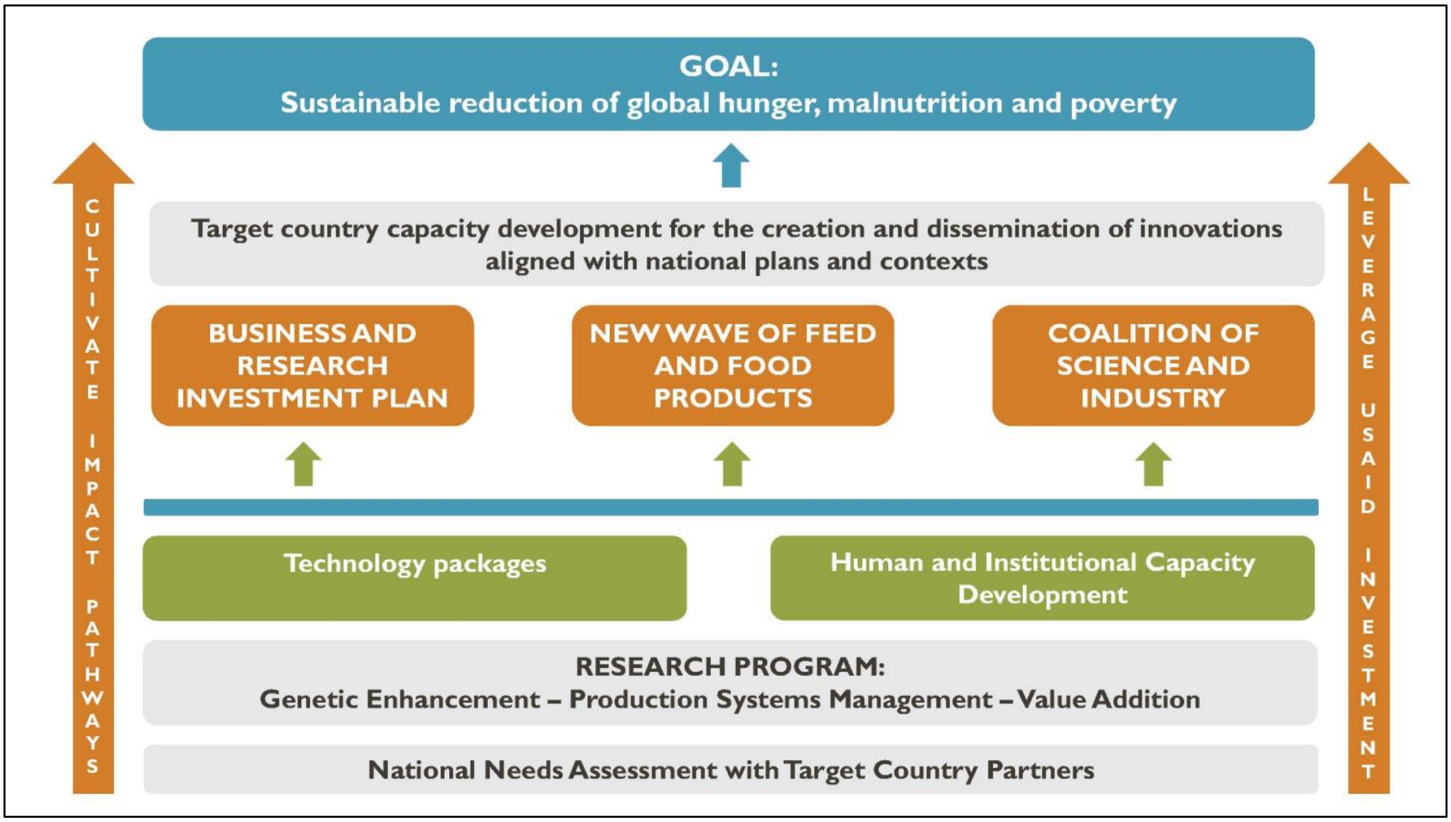



***Figure 2 Sorghum and Millet Innovation Lab Theory of Change***

The ToC embedded in the Sorghum and Millet Innovation Lab's activities is based on a "bottom up" approach of identification of needs and priorities derived from stakeholders along the sorghum and millet value chains. A competitive call for proposals was used to identify the innovative research projects to address these national identified needs.

Specific technology packages have been developed and there have been key successes in bringing them to a Phase 3 and Phase 4 level through multiple scaling pathways. The SMIL technology catalog can be found online at https://www.k-state.edu/smil/techcatalog/index.html. The technology catalog features technology packages and there are multiple technologies listed in the USAID Research Rack Up database. The management entity is also cultivating pathways to support uptake and scaling of technology packages. In Ethiopia, SMIL has allocated additional funds to support a seed multiplication, farmer demonstration, and media promotion of the registered *Merera* disease-resistant sorghum to accelerate uptake in western Ethiopia. This is further detailed as one of our success stories.

Local capacity development is an essential cross cutting component of the SMIL's ToC. SMIL 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, and internet/phone access. 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*

Our performance monitoring plan defines key components to help measure progress towards our mission and links to the program's ToC. Our high-level goal is to contribute towards the sustainable reduction of global hunger, malnutrition, and poverty through a country-led development of innovative technologies that will be scaled along the sorghum and millet value chains as well as long-term local capacity development.

Our bottom-up approach is based on country-specific and robust support of national capacity and planning for research that is demand-driven. In-country research prioritization meetings provided the opportunity to develop a stakeholder analysis, discuss strengths and weaknesses, and discuss research constraints during the initial phase of program establishment. These meetings helped to lay a strong foundation for full integration into national-level priorities. The selected project design and objectives all contribute to these national and regional priorities to enhance and build upon current initiatives.

Local and Institutional Capacity Development (LICD) is also central to the SMIL ToC. At the national level, strategic support of existing forums to strengthen strategic planning and implementation and monitoring will be provided. Continued support to develop, mentor, and establish well rounded national research teams who have strong technical research capacities along with skills to present, package, and lobby are being achieved.

Ongoing stakeholder analysis is another aspect of our ToC to better understand the actors, their interests, and their power and influence in relation to the sorghum and millet value chains. Engagement with the key stakeholders such as policy actors, development partners, and end users is vital and cross-country learning has provided opportunities for engagement with multiple international actors.

The SMIL ToC also recognizes that development context, enabling environment and change is an extremely complex process with multiple actors, social, economic, and political factors, and cultural context. A strong mechanism for feedback, lessons learned, and planning adjustment is in place to consider alternative approaches or ways of thinking.

SMIL has continued to assess the risk assumptions at country/zone level. Together, with in-country coordinators and national team members, SMIL has embraced an "adaptive management" philosophy of finding mitigation strategies in response to stresses such as COVID-19, political instability, security threats, retention of staff, accelerated climate change, etc.

The SMIL management entity continues to play an enabling role in development of global research teams that implement projects which are fully integrated into the national level research priorities. In addition to the long-term local capacity development outputs, technology packages are being co-created with end-users for further uptake. The SMIL management entity is leveraging multi-sector collaborations and USAID investment to further scale these technologies.

# Research Project Reports

## *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 these 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 (Assosa Agricultural Research Center, Bako Agricultural Research Center), Oromia Agricultural Research Institute, Haramaya University |

*Achievements*

The improved sorghum variety Merera was officially released in 2020 from intensive selection of the Ethiopian core collection. Demonstration of this variety is being conducted in five sorghum growing districts of Western Ethiopia, Oromia regional state. Five districts namely Boneya Boshe, WayuTuka, Guto Gida, Ilu Gelan and Chawaka from East Wollega, West Shewa and Buno Bedele Zones are selected based on their potential for sorghum production. From each district, a total of eight farmers were selected from different 'kebeles', the smallest administrative unit. A total of 40 farmers were involved for the demonstration of this technology. Demonstrations across districts at all farmers' fields showed excellent performance at the time of reporting. Farmers research group (FRG) consisting of 15 farmers were established at each kebele. This formalized group will be highly engaged in popularization of Merera.

Regional variety trials precede the variety verification trial in the Ethiopian to support the varietal development and approval scheme. During 2020 cropping season, 18 sorghum genotypes including two standard checks were evaluated under the regional variety trial at multiple locations. The data demonstrated that some genotypes produced high grain yield and displayed better foliar and panicle diseases resistance than the standard check. Two genotypes that produced high grain yield and disease tolerance will be promoted to varietal trials for potential release in 2022. The field performance of the genotypes was excellent. It is expected that, based on the combined 2020-2021 data, at least 1-2 best performing genotypes will be promoted to varietal trials in 2022 cropping season for possible variety release and registration.

The intensive characterization of the 358 Ethiopian core subset of sorghum landraces is being spearheaded in this project. Chemeda Birhanu's, a Ph.D. student under this project is responsible for the extensive data capture of this project in collaboration with personnel from EIAR and regional agricultural research centers. In the current season, the landraces, and appropriate checks (Assosa-1, Adukar, Dagim and Bonsa) were planted in partial replication in 1 row x 4m x 0.75m plot areas in row column arrangements at Bako, Jimma, Haramaya University and Assosa in 2021 cropping season. Most of these locations are characterized by high relative humidity, rainfall, and temperature that is conducive to screen for disease resistance. Haramaya represents the Eastern Ethiopian highlands where sorghum is widely grown and sorghum production in the region is impaired by anthracnose. High disease severity and incidence occurs at Haramaya.

*Capacity building*

Individuals trained under this project include:

| | | | |
|---|---|---|---|
| 12 | Haramaya University | Ph.D. | Plant pathology |
| 39 | Purdue University | Ph.D. | Plant pathology |
| 80 | EIAR, Assosa Research Center | Ph.D. | Plant pathology |

*Lessons learned*

The benefits of a consistent breeding, evaluation, and promotion program, combined with high quality phenotyping through dedicated students pursuing advanced degrees, is gaining momentum. The program has already produced high yielding varieties that have moved through the release process and are being tested and evaluated with farmers while seed multiplication is underway.

*Presentations and publications*

Dessalegn, K., Lule, D., Nida, H., Mekbib, F., Girma, G., & Mengiste, T. (2021). Evaluation of selected Ethiopian sorghum genotypes for resistance to anthracnose. *European Journal of Plant Pathology 2021*, 1–13. https://doi.org/10.1007/S10658-021-02386-6

Fu, F., Girma, G., & Mengiste, T. (2020). Global mRNA and microRNA expression dynamics in response to anthracnose infection in sorghum. *BMC Genomics 2020 21:1*, *21*(1), 1–16. https://doi.org/10.1186/S12864-020-07138-0

Girma, G., Nida, H., Tirfessa, A., Lule, D., Bejiga, T., Seyoum, A., Mekonen, M., Nega, A., Dessalegn, K., Birhanu, C., Bekele, A., Gebreyohannes, A., Ayana, G., Tesso, T., Ejeta, G., & Mengiste, T. (2020). A comprehensive phenotypic and genomic characterization of Ethiopian sorghum germplasm defines core collection and reveals rich genetic potential in adaptive traits. *The Plant Genome*, *13*(3), e20055. https://doi.org/10.1002/TPG2.20055

Mengiste, T., Ejeta, G., Tirfessa, A., Tessema, G., & Nida, H. (March 2021). Development of Ethiopian Sorghum Core Subset and its Potential Utilization. Presentation at SMIL 2021 Annual Conference, Virtual.

Mengiste, T., Tessema, G., & Nida, H. (March 2021). Genetic Resistance to Fungal Pathogens in Sorghum. Presentation at SMIL 2021 Annual Conference, Virtual.

Nida, H., Girma, G., Mekonen, M., Tirfessa, A., Seyoum, A., Bejiga, T., Birhanu, C., Dessalegn, K., Senbetay, T., Ayana, G., Tesso, T., Ejeta, G., & Mengiste, T. (2021). Genome-wide association analysis reveals seed protein loci as determinants of variations in grain mold resistance in sorghum. *Theoretical and Applied Genetics 2021 134:4*, *134*(4), 1167–1184. https://doi.org/10.1007/S00122-020-03762-2

Nida, H., Lee, S., Li, Y., & Mengiste, T. (2021). Transcriptome analysis of early stages of sorghum grain mold disease reveals defense regulators and metabolic pathways associated with resistance. *BMC Genomics 2021 22:1*, *22*(1), 1–17. https://doi.org/10.1186/S12864-021-07609-Y

## *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*
Phenotypic data generated on a subset of 358 Ethiopian sorghum landrace accessions for a study on drought tolerance. Data on response to drought was combined with GBS data to conduct GWAS for drought tolerance from which a marginally significant QTL was consistently detected.

Towards our effort to establish heterotic pools among Ethiopian sorghum landraces, a set of 108 hybrids were evaluated. Twenty-eight of them resulted in higher yield than the best check hybrid. The new hybrids showed potential for boosting productivity with higher yields as much as over 50% compared to the best local check hybrid. Nineteen landraces were identified as having high combining ability and as potential candidate parents that can be used in hybrid breeding program. This result is significant and important as baseline information for heterotic pool determination and parental line development based on landraces that have unique adaptation to local conditions. Moreover, 300 newly generated hybrids of Ethiopian landraces were planted for heterotic response determination. Genetic diversity analysis on 103 landrace B-lines and 457 landrace R-lines using 338,974 SNPs showed that the B and R line populations appeared to form clearly separated genetic pools that can potentially be grouped to complementary heterotic groups and predictably produce elite sorghum hybrids.

In our effort to promote and support the development of a sorghum hybrid seed system, progress has been made in the demonstration of hybrid seed production techniques to researchers and seed enterprises. Seed productions were undertaken by a range of seed units in the country. Notably, a large-scale hybrid seed multiplication was conducted over an area of 24 ha by a private company that produced over 70 quintals of hybrid seed. Educational programs were given to farmers on the agronomic and economic merits of hybrids. This was achieved through on-farm demonstration of released hybrids and farmers' field days.

*Capacity building*

Individuals trained under this project include:

| | | | |
|---|---|---|---|
| 44 | Purdue University | Post-doctoral studies | Plant breeding and pathology |
| 68 | Purdue University | Post-doctoral studies | Plant genetics |

*Lessons learned*

The biggest lesson is that peace, tranquility, and stability are essential for a nation at its prime stage of economic development. Unfortunately, Ethiopia has been in turmoil during the entire phase-II of the SMIL project. Initially, it was civil disturbance, mostly in Oromia, that limited staff mobility in the country, but this devolved into an all-out war in Tigray and Amhara, and the COVID-19 pandemic throughout the country.  Several experiment locations became inaccessible with the war in parts of Amhara and the entire Tigray region. Research staff in collaborating centers were among those displaced and their lives impacted, no matter how much they may have tried to work through these challenges. In consultation with the research staffs in the affected areas, new field experiment sites were identified, and a few trials were planted. Continuous discussions and consultations were held virtually to keep project activities running. It is near impossible to conduct crop breeding research during times of war and pandemic, though our collaborators showed great resilience and grit.

*Presentations and publications*

Adeyanju, A., Sattler, S., Rich, P., Rivera-Burgos, L., Xu, X., & Ejeta, G. (2021). Sorghum Brown Midrib19 (Bmr19) Gene Links Lignin Biosynthesis to Folate Metabolism. *Genes 2021, Vol. 12, Page 660*, *12*(5), 660. https://doi.org/10.3390/GENES12050660

Ejeta, G., Nida, H. (March 2021). Genetic Enhancement of Sorghum to Promote Commercial Seed Supply and Grain Market Development. Presentation at SMIL Administrative virtual meeting, Virtual

Nida, H., Girma, G., Mekonen, M., Tirfessa, A., Seyoum, A., Bejiga, T., Birhanu, C., Dessalegn, K., Senbetay, T., Ayana, G., Tesso, T., Ejeta, G., & Mengiste, T. (2021). Genome-wide association analysis reveals seed protein loci as determinants of variations in grain mold resistance in sorghum. *Theoretical and Applied Genetics 2021 134:4*, *134*(4), 1167–1184. https://doi.org/10.1007/S00122-020-03762-2

Nida, H., Lee, S., Li, Y. *et al.* Transcriptome analysis of early stages of sorghum grain mold disease reveals defense regulators and metabolic pathways associated with resistance. *BMC Genomics* 22, 295 (2021). https://doi.org/10.1186/s12864-021-07609-y

Rivera-Burgos, L., Volenec, J., & Ejeta, G. (2019). Biomass and Bioenergy Potential of Brown Midrib Sweet Sorghum Germplasm. *Frontiers in Plant Science*, *10*. https://doi.org/10.3389/fpls.2019.01142

## *Improving Sorghum Adaptation in West Africa with a Genomics-Enabled Breeding Network (SAWAGEN)*

*Led by*
Dr. Geoffrey Morris
*Colorado State University - USA*

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

### *Description*

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.

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).

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.

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):* | Colorado 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*

A critical first step for phase-II was to validate that the product concepts developed at the proposal stage met the needs of local stakeholders. All four breeding programs have now completed stakeholder validation of the varietal product concepts, based on feedback from multiple grower organizations in multiple regions in each country. Field breeding to generate and advance breeding lines towards varietal release has progressed largely as planned. Some delays have occurred due to adverse environmental conditions or problems with germplasm purity. Depending on the program and product concept, the breeders have advanced between 1–4 generations, out of a total of 6–8 generations that will be required to deliver varieties to the seed system. Marker genotyping was successfully conducted for all four breeding programs. Marker-assisted selection was conducted for three of the programs (For INRAN, marker genotyping revealed inconsistencies in the germplasm, which is being resolved prior to selection).

A key criterion for durability has been for NARS scientists to build strong collaborative relationships with each other (i.e., not just with US collaborators). The strength of the NARS collaborations is evidenced by the participation in our bimonthly ference calls. In the past project year, we met on 22 Zoom conference calls, with an average of seven participants (range: 4–10) and an average two NARS and two international partner institutions on each call. Importantly for durability of the network beyond the project, these conference calls are now coordinated and facilitated by Fanna Maïna, so the management of the network is increasingly based in Africa. Fanna Maïna was recently featured in the United Nations Integrated Strategy for the Sahel, called The Griot, and can be found at https://www.k-state.edu/smil/res_pubs/publications/TheGriot3rdEditionEN.pdf. A key research goal for phase-I, which continued into phase-II, was the discovery of drought tolerance alleles in West African germplasm for use in molecular breeding of drought tolerance. The development of molecular markers, which will facilitate selection of drought tolerance in West African sorghum, is now underway. Phase-II of SAWAGEN was designed with four interconnected research & development platforms, each led by an early-career NARS scientist. This approach appears to be quite successful.

*Capacity building*

Individuals trained under this project include:

| | | | |
|---|---|---|---|
| 70 | Universite Abdou Moumouni Niamey | Ph.D. | Crop Physiology |
| 71 | Universite Abdou Moumouni Niamey | Ph.D. | Crop Physiology |
| 72 | Colorado State University | Ph.D. | Plant breeding and genetics |

*Lessons learned*

Marker genotyping across the four breeding programs last year revealed inconsistencies in germplasm and unexpectedly low crossing rates in some programs. Therefore, early in the year we refocused efforts on institutional capacity for breeding program fundamentals, particularly seed lot purity, breeding line identity, and crossing efficiency. Our next round of marker genotyping, in the coming year, will give us feedback on where the institutional capacity for breeding program fundamentals is sufficient and where further improvements are needed.

*Presentations and publications*

Akata A., Soule B., Djagni S., & Tchalla K. (March 2021). A Gender Analysis Reveals Varietal Preferences and Production Constraints Among Smallholder Sorghum Farmers in Togo. Presentation at SMIL 2021 Annual Conference, Virtual.

Diatta, C., Sarr, M., Tovignan, T., Aidara, O., Dzidzienyo, D., Diatta-Holgate, E., Faye, J., Danquah, E., Offei, S., & Cisse, N. (2021). Multienvironment Evaluation of Tannin-Free Photoperiod-Insensitive Sorghum (Sorghum bicolor (L) Moench) for Yield and Resistance to Grain Mold in Senegal. *International Journal of Agronomy*, *2021*. https://doi.org/10.1155/2021/5534314

Diatta, C., Bodian, S., Faye, J., Gaye, D., Fayihoun, C., Sine, B., Morris, G., & Cisse, N. (March 2021). Sorghum Lines Combining Higher Yield and Grain Mold Resistant Moving to On-Farm Trials in Senegal. Presentation at SMIL 2021 Annual Conference, Virtual.

Falalou, H., Abdou, H., Inoussa, S., Ouba, M., Fanna, H., & Morris, G. (March 2021). Does Lysimeter Phenotyping Reflect Field Phenotyping in Niger? Presentation at SMIL 2021 Annual Conference, Virtual.

Faye, J., Akata, J., Sine, B., Diatta, C., Fonceka, D., Cisse, N., & Morris, G. (March 2021). Genomics analyses reveal drought tolerance loci in African sorghum germplasm. Presentation at SMIL 2021 Annual Conference, Virtual.

Faye, J., Maïna, F., Akata, E., Sine, B., Diatta, C., Mamadou, A., Marla, S., Bouchet, S., Teme, N., Rami, J., Fonceka, D., Cisse, N., & Morris, G. (2021). A genomics resource for genetics, physiology, and breeding of West African sorghum. *Plant Genome*, *14*(2). https://doi.org/10.1002/TPG2.20075

Faye, J., Maïna, F., Akata, E., Sine, B., Diatta, C., Mamadou, A., Marla, S., Bouchet, S., Teme, N., Rami, J., Fonceka, D., Cisse, N., & Morris, G. (2020). A Genomics Resource for Genetics, Physiology, and Breeding of West African Sorghum. bioRxiv 2020.06.03.132217. https://doi.org/10.1101/2020.06.03.132217

Faye, J., Akata, E., Sine, B., Diatta, C., Cisse, N., Fonceka, D., & Morris, G. (2021). Quantitative and population genomics suggest a broad role of staygreen loci in the drought adaptation of sorghum. *BioRxiv*, 2021.06.09.447769. https://doi.org/10.1101/2021.06.09.447769

Maïna, F., Harou, A., Hamidou, F., & Morris, G. (March 2021). Association Genetics in West-African Sorghum Reveals Several Loci Underlying Drought Tolerance at Flowering Stage. Presentation at SMIL 2021 Annual Conference, Virtual.

Morris, G. (March 2021). SAWAGEN: Improving Sorghum Adaptation in West Africa with a Genomics-Enabled Breeding Network. Presentation at SMIL 2021 Annual Conference, Virtual.

Muleta, K., Felderhoff, T., Winans, N., Walstead, R., Charles, J., Armstrong, J., Mamidi, S., Plott, C., Vogel, J., Lemaux, P., Mockler, T., Grimwood, J., Schmutz, J., Pressoir, G., & Morris, G. (2021). The recent evolutionary rescue of a staple crop depended on over half a century of global germplasm exchange. *BioRxiv*, 2021.05.11.443651. https://doi.org/10.1101/2021.05.11.443651

Ousseini, A., Mamadou, A., Maïna, F., & Morris, G. (March 2021). SAWAGEN breeding activities for striga tolerance using Nigerien sorghum land race: Mota Maradi (MM), Matche Da Koumgna (MDK) and SRN39. Presentation at SMIL 2021 Annual Conference, Virtual.

Sambakhé D., Sine B., Ndiaye M., Diatta C., Faye J., Fonceka D., & Morris G. (March 2021). Crop Modeling Suggests That Water Deficit Is Not Always the Most Important Abiotic Factor Limiting Sorghum Yield in Senegal. Presentation at SMIL 2021 Annual Conference, Virtual.

***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 Sudan grass 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*
Sorghum has lower protein digestibility compared to other cereals. The Protein Digestibility Lab established in Senegal by Elisabeth Diatta-Holgate is serving as a hub of activity for efforts to identify genes that control protein digestibility in sorghum. Mutation studies identified two sorghum mutants with 23-37% more digestible proteins than normal sorghum. Whole genome sequencing was used to discover candidate SNPs for the protein digestibility traits in SbEMS1613 and

SbEMS3324. Large-scale mapping studies are being conducted at Purdue to identify the causal mutations and genes responsible for these changes in protein digestibility. Sorghum breeding efforts for protein digestibility are focused on incorporating genes for improved protein digestibility into locally adapted cultivars. The hl locus is being incorporated into ISRA 621A, ISRA 621B, ISRA 622A, ISRA 622B. The ten best progenies derived in the Faourou genetic background were tested in multi-location trials. Grain samples collected from each location were used to test and validate changes in grain quality attributes of these varieties.

A new forage breeding program was founded in Niger by Dr. Ousmane Seyni Diakite. Dr. Diakite established the program at the INRAN/CERRA/NIAMEY facility. Laboratory facilities include a dry lab for seed preparation and a new cold facility for seed storage. The breeding nurseries are being managed at the Cerra Ny and Cerra Mdi locations and multi-location trials to optimize the testing program. The bmr6 and bmr12 genes are being introgressed (BC1F5 and F6) into elite Nigerien OPVs and breeding lines in the breeding program. Participatory plant breeding trials showed that farmers preferred SEPON82 derivatives compared to other genotypes. Dr. Diakite, with backstopping from Purdue, is also introgressing the brown midrib traits into locally adapted seed parents and pollinator parents for hybrid development.

### *Capacity building*

Individuals trained under this project include:

| | | | |
|---|---|---|---|
| 73 | University Cheikh Anta Diop | Master's | Plant and microbial biotechnology |
| 79 | University Cheikh Anta Diop | Master's | Plant and microbial biotechnology |

### *Lessons learned*

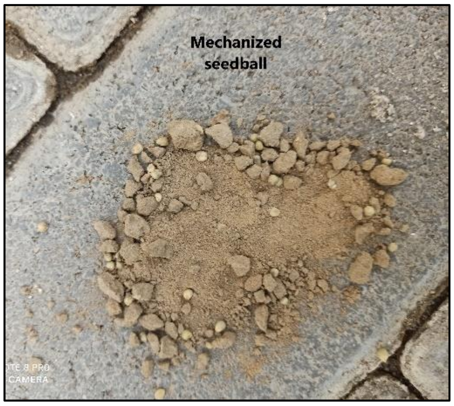
Tremendous progress was made in efforts to improve sorghum grain and forage quality traits. Although locally adapted sorghum varieties from West Africa showed low protein digestibility, the genetic mutants SbEMS1613 and SbEMS3324 exhibited 23-37% more digestible proteins than conventional sorghum.  Ten promising lines with good adaptation, food-grade quality, and highly digestible protein were identified in the Faourou background in multi-location trials. These lines are being advanced in trials in 2021. Parallel breeding efforts to convert Nguinthe, Nganda, and Darou for highly digestible protein traits are advancing at a similar pace.

The sorghum research program in Niger is making excellent progress in establishing a forage breeding effort in INRAN. OPVs with good adaptation and forage quality attributes have been identified in multi-location trials. Farmers exhibited preference for many of the new brown-midrib breeding lines over the local varieties for forage production. Locally adapted parent lines with brown midrib traits are being developed to support hybrid development efforts.

### *Presentations and publications*

Griebel, S, Adedayo, A, Tuinstra, M. Genetic diversity for starch quality and alkali spreading value in sorghum. *Plant Genome*. 2021; 14: e20067. https://doi.org/10.1002/tpg2.20067

Tuinstra, M. (March 2021). Sorghum Trait Deployment Pipeline for Improved Food and Feed Value. Presentation at SMIL 2021 Annual Conference, Virtual.




### *Seed balls - Enhancing 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 seedling 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 continues to refine develop and dissemination of the seed ball 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 focused on mechanization of the seed ball construction process. Dissemination is based on collaboration with farmer federations (Fuma Gaskiya, Mooriben) 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*
The project is completely in time with respect to project progress. Not all key targets could be reached (e.g., on-farm field trials) due to the COVID-19 pandemic, but sufficiently high numbers of trials that can be scientifically evaluated were completed. The technology can be transferred to sorghum, and this was published. Field trials in this respect are on-going, especially in the Falwel region. A farmer exchange between farmers of the Mooriben, Falwel and Tera groups was organized and guided by experienced extensionists (Dr. Oumarou INRAN, Mr. Aminou, Fuma Gaskiya). The seed ball technology is tested in two other R4D projects (Women's field, CATI-GAO, both McKnight-funded). An additional budget request was submitted to the SMIL steering group to allow the organization of a "National Seed Ball Conference" to introduce the technology to a wider group of stakeholders and actors.

The last greenhouse trial has started (seed ball effect under water stress). An additional greenhouse trial is planned on bio-fortification of seed balls. A last set of soil samples are under analysis to detect seed ball effect depending on soil properties. A concept on the economic evaluation of seed balls was developed by KSU. An adoption study was conducted interviewing about 480 farmers. The subsequent QAToCA-study is underway. Three scientific papers on the technology have been published/are accepted for publication. More information on this project can be found at https://projekte.uni-hohenheim.de/seedball. A scientific training was organized for 12 students from the Maradi region, applying the seed ball technology for their field of study.

*Capacity building*

Individuals trained under this project include:

| | | | |
|---|---|---|---|
| 53 | University of Hohenheim | Master's | Soil science/Agronomy |
| 54 | University of Hohenheim | Post-Doctoral studies | Soil science/Agronomy |
| 74 | University of Hohenheim | Master's | Agritropics |
| 81 | University of Hohenheim | Master's | Agricultural Engineering |

*Lessons learned*

The most impressive lesson learned is that the national partners in the project have reached such a high level of performance with respect to the seed ball technology that external forces do not lead to a breakdown of research for development activities. This could be achieved through long-term co-operation.  Therefore, R4D funding should not change the topic every 2-3 years but envisage longer funding schemes. Otherwise, innovations cannot be researched in such a detail that meaningful recommendations can be given when and where to best place them. Short-term funding leads to adoption failure. Farmers need to be trained several times on the same technology until they understand how to practice it. A second major lesson learned is that technologies that require less workload and create a lower cropping risk, but with only moderate yield effects, are more easily accepted by women. On the other hand, male farmers frequently asked for mechanization of the technology.

Security issues in the west and east of the Niger are a rising concern and could reach a level that hamper project activities. Technology transfer to sorghum is promising and seed balls could be applied to other small grain wide-spaced crops, too.

*Presentations and publications*

Herrmann, L., Nwankwo, C. (March 2021). Seed balls - Enhancing the yield effect in pearl millet and sorghum and disseminating the technology in West Africa. Presentation at SMIL 2021 Annual Conference, Virtual.

Jesser, A., Romuli, S., & Nwankwo, C. (March 2021). Mechanisation of Seed Ball Production in The Sahel. Presentation at SMIL 2021 Annual Conference, Virtual.

Moussa, H., Nwankwo, C., Aminou, A. et al. Sanitized human urine (Oga) as a fertilizer auto-innovation from women farmers in Niger. Agron. Sustain. Dev. 41, 56 (2021). https://doi.org/10.1007/s13593-021-00675-2

Nwankwo, C. I., & Herrmann, L. (2021). Optimisation of the seedball technology for sorghum production under nutrient limitations. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *122*(1), 53–59. https://doi.org/10.17170/KOBRA-202102113204

## *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*
Sorghum flours of smooth, uniform particle size were shown to perform better in different products, especially batter-based products like injera and pancakes. This indicates that mills that produce a more uniform, narrow particle size sorghum flour would be more appropriate for commercialized sorghum products due to the more predictable product quality they provide. In general, roller and disc mills produced better quality products than hammer milled flour. Eleven industry partners committed to working with us on product testing in the next period. We also developed sorghum malting and quality testing protocols that produce consistent results.

The improved functionality HD sorghums were successfully grown in Ethiopia this year and are close to harvest. Three varieties were grown, two of these are expected to produce enough grain for the food science team to test industry processing partners. Bulk grain production was also implemented in Texas and harvesting in south/central Texas is progressing, whereas harvest in North Texas will occur in late September – October.

A novel finding was that the HD sorghums produced stronger gels during cooking than their wild-type counterparts, for both normal and waxy starch backgrounds. Interestingly, the stronger gels of the HD sorghum also had lower syneresis (water separation) during one-week storage at 4°C than the wild-type sorghum gels. This behavior was unexpected because strong gels during storage generally indicate more starch retrogradation, which is typically accompanied by more syneresis. The evidence thus suggests that the stronger HD sorghum gels are stabilized by starch-protein network which makes them less prone to retrogradation (which normally leads to product staling). Thus, the HD trait could lead to novel sorghum application in various foods where strong, stable gels are desirable.

*Capacity building*

One MS student has been recruited at Hawassa University; start of research was delayed due to COVID-19 shutdown of the University. Another graduate student is undergoing training through project activities at EIAR. One Graduate student recruited at TAMU, initiated studies in the fall of 2020.

*Lessons learned*

The persistent global COVID-19 pandemic has disrupted research activities and overall productivity beyond what we had imagined initially. Most of our work requires coordinated hands-on in-doors activities in close contact to execute, and remote engagements cannot compensate. However, we learnt to conserve resources and used the downtime to have infrastructure and facilities in place, ready to execute delayed tasks as soon as situation allows. With the rapid availability of vaccines, we anticipate the next half of the year will present a more positive outlook for both fieldwork and processing activities. Key tasks, including laboratory quality trials and bulk grain production have been initiated to enable more rapid progress this year.

*Presentations and publications*

Awika, J. (March 2021). Advancing improved functionality and protein quality sorghum hybrids for food applications in Ethiopia. Presentation at SMIL 2021 Annual Conference, Virtual.

Adebowale, O., Taylor, J., & de Kock, H. (2020). Stabilization of wholegrain sorghum flour and consequent potential improvement of food product sensory quality by microwave treatment of the kernels. *LWT*, *132*, 109827. https://doi.org/10.1016/J.LWT.2020.109827

Mezgebe, A., Taylor, J., & de Kock, H. Influence of waxy (high amylopectin) and high protein digestibility traits in sorghum on injera sourdough-type flatbread sensory characteristics. Foods 2020, 9, 1749. https://doi.org/10.3390/FOODS9121749

Mezgebe, A., Abegaz, K. (March 2021). Malted Sorghum Brewing Potentials of Local and Novel Sorghum Lines. Presentation at SMIL 2021 Annual Conference, Virtual.

Scott, G., Awika, J. (March 2021). Effect of High-Digestibility (HD) and Waxy Starch Traits on Sorghum Functionality in Chemically Leavened Batter System. Presentation at SMIL 2021 Annual Conference, Virtual.

## *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-II, 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*

In Niger, there were scale-up activities in this period for the Hub-and-Spoke Food Innovation System, jointly developed by SMIL and the McKnight Foundation. Three "secondary" rural Spokes were established near primary ones, and all are now beginning to process and sell products. Also, new Spoke Food Innovation Centers were established in Burkina Faso and Mali under the McKnight project. Processing and sales data for 2020 for rural and urban processors associated with the INRAN Hub showed very good activities for the urban processors, particularly for the INRAN-SMIL incubated ETC processor with sales in over 40 stores. Rural Spokes processed and sold product despite difficulties related to travel restrictions due to the COVID-19 pandemic and security issues.

Research at ITA/Dakar and INRAN/Niamey advanced new millet and sorghum products developed at the food technology research centers. In Niger, sensory evaluations conducted at four rural sites and in Niamey showed good acceptability and texture of extruded fortified couscous-like products, *lakiri* (millet, peanut) and *tousme* (whole grain biofortified millet, moringa) compared to the traditionally prepared products. In Senegal, progress was made, in partnership with ISPA-CNR Bari, Italy, on development of a fermentation culture to be used in commercial processing of economic couscous for the Dakar and other urban markets, and in the development of fast-cooking *arraw*, a popular Senegalese starchy staple food. Dakar processors have been engaged in development of both products and extending these technologies will be the next step. The sensory testing facility at ITA in Senegal is complete and certified sensory training for Dr. Cheikh N'diaye will take place in fall 2021. Detailed shelf-life study designs have been made and planned studies will take place in 2021 in Niger and Senegal.

*Capacity building*

Individuals trained under this project include:

| | | | |
|---|---|---|---|
| 51 | Purdue University | Ph.D. | Food Science |
| 58 | Cheikh Anta Diop University | Ph.D. | Microbiology |
| 75 | University of Tillaberi | Master's | Nutrition |
| 76 | Cheikh Anta Diop University | Ph.D. | Food Science and Technology |
| 77 | Cheikh Anta Diop University | Ph.D. | Food Science and Technology |
| 79 | Cheikh Anta Diop University | Master's | Plant and Microbial Biotechnology |

*Lessons learned*

The self-initiated (or organic) growth of the rural Spoke Food Innovation Centers to outlying communities/villages resulted in formally established secondary spokes. With training by the INRAN Hub and primary spokes, as well as modest investment in basic food processing equipment, these new sites have become viable new women's association of processors. This demonstrates a natural resilience of the system and even in stressed period as present due to the COVID-19 pandemic.

*Presentations and publications*

Diouf, A., Sarr, F., Ndiaye, C., Ayessou, N., Ayessou, N., & Fall, S. (n.d.). Improving Nutritional Quality of Cowpea (Vigna unguiculata) by Soaking Process Caractérisation biochimique de quelques variétés de sésame produites au Sénégal View project Impact of a new solar dryer prototype on provitamin A recovery View project Improving Nutritional Quality of Cowpea (Vigna unguiculata) by Soaking Process. *International Journal of Food Science and Nutrition Engineering*, *2020*(1), 37–41. https://doi.org/10.5923/j.food.20201001.03

Ferruzzi, M., Kruger, J., Mohamedshah, Z., Debelo, H., & Taylor, J. (2020). Insights from in vitro exploration of factors influencing iron, zinc and provitamin A carotenoid bioaccessibility and intestinal absorption from cereals. *Journal of Cereal Science*, *96*, 103126. https://doi.org/10.1016/J.JCS.2020.103126

Hayes, A., Gozzi, F., Diatta, A., Gorissen, T., Swackhamer, C., Bellmann, S., & Hamaker, B. (2021). Some pearl millet-based foods promote satiety or reduce glycaemic response in a crossover trial. British Journal of Nutrition, 126(8), 1168-1178. https://doi:10.1017/S0007114520005036

Hamaker, B., Moussa, M. (March 2021). Expanding markets for sorghum and millet farmers in West Africa through strengthening of women and youth processors and nutrition-based promotion of products. Presentation at SMIL 2021 Annual Conference, Virtual.

Hamaker, B. R., Martinez, M., Swackhamer, C., Mennah-Govela, Y., Diatta, A., Bornhorst, G., & Hayes, A. (January 2020). Pearl millet (Pennisetum glaucum) couscous breaks down faster than wheat couscous in the Human Gastric Simulator, though has slower starch hydrolysis(pp.111-122). Food & Function, 11, Cambridge, England. https://doi.org/10.1039/c9fo01461f

Hayes, A. Gozzi, F., Diatta, A., Gorissen, T., Swackhamer, C., Bellmann, S., Hamaker, B. (2020). Some pearl millet-based foods promote satiety or reduce glycaemic response in a crossover trial. British Journal of Nutrition, I-I I. https://doi.org:10.1017/S0007114520005036

Moussa, M. & Hamaker, B. (March 2021). Women Groups Becoming Food Innovators and Transforming Rural Community in Niger and West Africa. Presentation at SMIL 2021 Annual Conference, Virtual and at Grand Hotel, Niamey, Niger.

Hamaker, B., Ayessou, N. (March 2021). Improving Nutritional Quality of Cowpea (Vigna unguiculata) by Soaking Process. Presentation at SMIL 2021 Annual Conference, Virtual.

Diouf, A., Ndiaye, C., Ferruzzi, M., Moussa, M., Hamaker, B., Ferruzzi, M., Oumarou, A., Yaye, H., Kafougou, Y., & Lamsso, H. (March 2021). Innovative Process of Making Instant Millet Fura (thin porridge) for West African Markets. Presentation at SMIL 2021 Annual Conference, Virtual and at Grand Hotel, Niamey, Niger.

Ndiaye, A., Ndiaye, C., Traore, D., Ferruzzi, M., Hamaker, B., & Cisse, M. (March 2021). Fermentation of Millet "Economic" Couscous Using Lactic Acid Strains. Presentation at SMIL 2021 Annual Conference, Virtual.

Traore, D., N'Diaye, C., Sene, A., & Seck, M. (March 2021). Millet Instant Rolled Flour "Arraw" Using Extrusion and Edible Hydrocolloids. Presentation at SMIL 2021 Annual Conference, Virtual.

**_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 (Ph.D. 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*

Seeds of open-pollinated and hybrid pearl millet varieties were produced, and progenies evaluated during the rainy season across 18 sites in Senegal and 5 locations in Niger. At least 160 farmers visited these plots in Senegal and identified panicle length, grain yield, stay green, and resistance to biotic stress such as Striga, downy mildew and drought as the most important traits when selecting a pearl millet variety to grow in their field.

Based on agronomic performance and farmers' appreciation, three open-pollinated varieties (SL 169, SL 423, and SL 28) and one hybrid (TAAW) have been proposed for release. The release committee will meet normally before the end of June 2021 to evaluate the technical report. Pearl millet lines for Striga, downy mildew; roots-related traits in Senegal and Niger were phenotyped and segregated. For Striga, the protocol allowed the breeding program to screen 200 inbred lines. New Striga resistant lines were identified that can be used in the NARS pearl millet breeding program.

The Open Sim Root model already being used in maize was calibrated for pearl millet through the implementation of some measured traits using Souna 3 variety. In addition, we established a protocol for high-throughput field root phenotyping pipelines (Root architectural and anatomical phenotyping in pearl millet). For UAV high throughput phenotyping, the calibration last rainy season was validated. The BCNAM mapping population was advanced from BC1F1 to BC1F2. For population improvement, recurrent selection was applied to 3 OPVs. A total of 444 S3/F4 lines were derived from these different populations. Test crosses (275 inbred lines crossed with a CMS line) showed that only 13% of them were fertile F1 and can be considered as a true hybrid. Some of these promising hybrids are being grown in the field currently to confirm their fertility before their preliminary yield evaluation during the rainy season. Eight of them produced more than 2 t/ha.

*Capacity building*

Individuals trained under this project include:

| | | | |
|---|---|---|---|
| 72 | Colorado State University | Ph.D. | Plant breeding and genetics |
| 88 | Ecole Nationale Supérieure d'Agriculture | Engineer | Agricultural Engineering |

*Lessons learned*

Using routinely new tools and methods helps breeders to rapidly and precisely select more lines to advance or reject based on criteria defined in their breeding product profile. Farmers appreciate and want the new varieties.

*Presentations and publications*

Serba, D., Sy, O., Sanogo, M., Issaka, A., Ouedraogo, M., Ango, I., Drabo, I., & Kanfany, G. (2020). Performance of dual-purpose pearl millet genotypes in West Africa: Importance of morphology and phenology. *African Crop Science Journal*, *28*(4), 481–498. https://doi.org/10.4314/acsj.v28i4.1

Serba, D., Yadav, R., Varshney, R., Gupta, S., Mahalingam, G., Srivastava, R., Gupta, R., Perumal, R., & Tesso, T. (2020). Genomic designing of pearl millet: A resilient crop for arid and semi-arid environments. *Genomic Designing of Climate-Smart Cereal Crops*, 221–286. https://doi.org/10.1007/978-3-319-93381-8_6

Kane, N. (March 2021). Genetic Enhancement of Pearl Millet for Yield, Biotic and Abiotic Stress Tolerance in West Africa (GENMIL). Presentation at SMIL 2021 Annual Conference, Virtual.

Niang, S., Diao, Y., Mbengue, S., Diack, O., Fall, S., Sy, O., Kane, N., & Kanfany, G. (March 2021). Identification of Potential Restorer and Maintainer Inbred Lines for West and Central Pearl Millet Hybrid Breeding Programs. Presentation at SMIL 2021 Annual Conference, Virtual.

Seck. E., Diao, Y., Drame, N., Diack, O., Fall, S., Sy, O., Kane, N., & Kanfany, G. (March 2021). Identification of Sources of Resistance to Striga Hermonthica in Pearl Millet (Pennisitum Glaucum (L.) R. Brown) inbred lines. Presentation at SMIL 2021 Annual Conference, Virtual.

Soulé, I., Issoufou, K., Halilou, H., Karimou, I., & Ibrahim, H. (March 2021). Development Of Downy Mildew (Sclerospora Graminicola) Resistant Pearl Millet [Pennisetum Glaucum (L.) R. Br.] Varieties for Sahelian Zones. Presentation at SMIL 2021 Annual Conference, Virtual.

## *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)<br>*Niger* - Institut National de la Recherche Agronomique du Niger (INRAN), University of Tillaberi |

*Achievements*
We were able to complete and publish the results of the extensive disease survey in Senegal, which included information on temperatures, rainfall, and soil type at each of the 206 geo-referenced sites visited. In both Niger and Senegal, hot spots for specific diseases identified were used to test local or US cultivars for disease response. In Senegal samples of C. sublineola (anthracnose) and long smut were collected and have been purified for eventual DNA-based diversity study. In both countries seed collected from cultivars tin the surveyed fields were collected and sent to Dr. Louis Prom for growth, first in quarantine and subsequently for disease response versus Texas anthracnose isolates. Both countries have advanced at least two crosses between local adapted cultivars and SC748-5 which is anthracnose-resistant in Texas as the first step in enhancing disease resistance using gene tagging. Niger was able to organize and delegate projects for participants at INRAN and the Université de Tillabéri, including training for conducting 'field days' when COVID-19

control permits. The response of Senegalese cultivars available in the US germplasm collection were surveyed for response to anthracnose and single nucleotide polymorphism associated with disease response were identified.

Seed collected from cultivars in both countries were grown in Dr. Prom's quarantine greenhouse and new seed collected for use in disease testing versus Texas isolates of pathogens. Thus far, only head smut tests which require a full life cycle have been started. Leaf samples for DNA extraction were also collected; most were acceptable for sequencing, but some were degraded so new plants have been grown to include those cultivars also. All samples need to be sequenced in the same reaction to avoid excessive costs.

*Capacity building*

Individuals trained under this project include:

| | | | |
|---|---|---|---|
| 69 | University of Tillaberi | Master's | Plant Pathology/Plant Breeding |
| 86 | Texas A&M University | Ph.D. | Plant Pathology and Microbiology |

*Lessons learned*

There is some question if sorghum cultivar SC748-5 is resistant to isolates of C. sublineola in the hot spot in Senegal. Some progress can be made despite restrictions on travel and gatherings, but the slowdowns impinge data collection so are likely to have significant effects on future planned activities. It is extremely difficult and expensive to send DNA extraction kits to Senegal.

*Presentations and publications*

Diatta, C., Magill, C., Prom, L., Haougui, A., Mame, S., & Adamou, I. (March 2021). Major Diseases of Sorghum and Niger. Presentation at SMIL 2021 Annual Conference, Virtual.

Magill, C., Prom, L., Haougui, A., Abdoulaye, A., Adamou, I., & Ali, O. (March 2021). Response of the Set of Anthracnose Differentials to Other Foliar and Panicle Diseases in Niger. Presentation at SMIL 2021 Annual Conference, Virtual.

Magill, C., Prom, L., Haougui, A., Adamou, I., Karimou, I., & Abdooulkadri, I. (March 2021). Survey of the Prevalence and Incidence of Foliar and Panicle Diseases of Sorghum Across Production Fields in Niger Poster. Presentation at SMIL 2021 Annual Conference, Virtual.

Prom, L., Sarr, M., Diatta, C., Ngom, A., Aïdar, O., Cisse, N., & Magill, C. (2020). The Occurrence and Distribution of Sorghum Diseases in Major Production Regions of Senegal, West Africa. *Plant Pathology Journal*, *20*(1), 1–10. https://doi.org/10.3923/PPJ.2021.1.10

Prom, L., Cuevas, H., Isakeit, T., & Magill, C. (2020). Screening Sorghum Accessions for Resistance against Anthracnose and Grain Mold through Inoculating with Pathogens. *Journal of Experimental Agriculture International*, *42*(1), 73–83. https://doi.org/10.9734/JEAI/2020/V42I130453

Prom, L., Sarr, M., Diatta, C., Ngom, A., Aïdar, O., Cisse, N., & Magill, C. (2020). The Occurrence and Distribution of Sorghum Diseases in Major Production Regions of Senegal, West Africa. *Plant Pathology Journal*, *20*(1), 1–10. https://doi.org/10.3923/PPJ.2021.1.10

Ahn, E., Prom, L., Hu, Z., Odvody, G., & Magill, C. (2021). Genome-wide association analysis for response of Senegalese sorghum accessions to Texas isolates of anthracnose. *Plant Genome*, *14*(2). https://doi.org/10.1002/TPG2.20097

Magill, C. (March 2021). Enabling Marker Assisted Selection for Sorghum Disease Resistance in Senegal and Niger. Presentation at SMIL 2021 Annual Conference, Virtual.

# Associate Award Project Report

***FTFIL for Genomics-Assisted Sorghum Breeding***

Award number: AID-OAA-LA-16-00003
*Now:* "Durable adaptation to aphid and drought for smallholder sorghum in the Americas"

*Led by*

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

*Location (Department Level)*
Haiti

*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).

*Launch of Haiti project: "Durable adaptation to aphid and drought for smallholder sorghum in the Americas"*
When the associate award ended in 2021, the Management Entity developed a follow-on project to ensure continuity. This project, "Durable adaptation to aphid and drought for smallholder sorghum in the Americas" will extend the work started under the associate award. This project will ensure that innovations on aphid and drought resilient varieties by the UniQ sorghum program led to durable solutions for smallholder farmers and downstream stakeholders in Haiti. Further, we will develop technology to facilitate the diffusion of the technology from Haiti to other smallholder-serving breeding programs in Latin America and beyond. The project launched in the second quarter of 2021 and has been progressing on schedule. The US-based members of the project team have been recruited and onboarded, the project team in the US and Haiti have been meeting regularly. The Haiti team has conducted their field activities on schedule despite the political unrest and security problems in Port-au-Prince, the earthquake in the south (near the breeding station in Cayes), and the move of the program from Port-au-Prince to Mirebalais.

*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*

A follow-on project to the associate award was initiated. The project is developing new aphid resistance marker technology, to further reduce aphid damage and mitigate the possibility that the RMES1 gene is overcome by the aphid. Genotype and phenotype data collection for aphid resistance in the UniQ program was completed, and initial mapping of new aphid-resistance loci should be completed by the first quarter of 2022. Similarly, we are identifying new drought tolerance loci based on field phenotyping of drought response in the UniQ program. To understand the role of dhurrin, a cyanogenic glycoside, in the stay-green post-flowering drought tolerance of UniQ germplasm we have been testing and improving low-cost assays cyanogenic potential (cyanide production). Using the same aphid and drought phenotype data, we will be testing hypotheses on potential tradeoffs and limitations of the current aphid and drought resilience traits used by UniQ, so we can develop breeding strategies that circumvent these issues

*Capacity building*

Individuals trained under this project include:

| | | | |
|---|---|---|---|
| 67 | Cornell University | Ph.D. | Plant breeding and genetics |

An additional aim of the project was to train the next generation of US researchers for careers in smallholder-serving R&D. A MSc student (female; Kristen Johnson; 05/21–) and a postdoc (male; Brian Rice; 10/21–) have been recruited onto the project, and an additional Ph.D. student (male; Carl VanGessel; 07/21–) funded by a CSU fellowship, is also participating on the project. Kristen is testing hypotheses on the role of the cyanogenic glycoside dhurrin in UniQ's drought tolerance and stay-green traits, which will provide critical information to guide the UniQ breeding program (and others) on potential tradeoffs for forage quality and drought tolerance. Brian is developing and implementing new genomic methods that will accelerate UniQ's genetic gain for complex interrelated traits (aphid resistance, drought tolerance, forage quality, grain, and forage yield) and facilitate the transfer of useful traits to other smallholder-serving programs. Carl is working to understand the genetic and physiological basis of the *RMES1* aphid resistance used by UniQ, to head-off any tradeoffs or vulnerabilities in this defense mechanism and facilitate the discovery of new resistance mechanisms. We're also working closely with early-career faculty member Terry Felderhoff (Kansas State University), leveraging funding from Innovative Seed Systems (e.g., Dekalb sorghum brand), to develop new aphid-resistance marker technology that will combat the aphid across the Americas.

*Lessons learned*

Initial scientific advances on sugarcane aphid resistance have generated strong interest from other areas of the world. This interest will lead to global public goods and spill-in benefits to the United States.

*Presentations and publications*

Jensen, S., Charles, J., Muleta, K., Bradbury, P., Casstevens, T., Deshpande, S., Gore, M., Gupta, R., Ilut, D., Johnson, L., Lozano, R., Miller, Z., Ramu, P., Rathore, A., Romay, M., Upadhyaya, H., Varshney, R., Morris, G., Pressoir, G., & Ramstein, G. (2020). A sorghum practical haplotype graph facilitates genome-wide imputation and cost-effective genomic prediction. *The Plant Genome*, *13*(1), e20009. https://doi.org/10.1002/TPG2.20009

## Other Publications from Phase-I Projects

Duressa, D., Bean, S., Amand, P. st., & Tesso, T. (2020). Identification of variant α-kafirin alleles associated with protein digestibility in grain sorghum. *Crop Science*, *60*(5), 2467–2478. https://doi.org/10.1002/CSC2.20198

Karimoune, L., Ba, M., Baoua, I., & Muniappan, R. (2020). Field performance of the parasitoid wasp, Trichogrammatoidea armigera (Hymenoptera: Trichogrammatidae) following releases against the millet head miner, Heliocheilus albipunctella (Lepidoptera: Noctuidae) in the Sahel. *BioControl 2020 65:4*, *65*(4), 389–399. https://doi.org/10.1007/S10526-020-10015-0

Serba, D., Sy, O., Sanogo, M., Issaka, A., Ouedraogo, M., Ango, I., Drabo, I., & Kanfany, G. (2020). Performance of dual-purpose pearl millet genotypes in West Africa: Importance of morphology and phenology. *African Crop Science Journal*, *28*(4), 481–498. https://doi.org/10.4314/acsj.v28i4.1

# Human and Institutional Capacity Development

Local and institutional capacity development is a core outcome of the Sorghum and Millet Innovation Lab's global research for development network. The program has been able to develop a network of global talent, resources, and capacity to address country-specific technology and development issues. Most of the 90 SMIL/USAID sponsored long-term training students have completed their degrees and are now back in country contributing to the research community as they engage in their respective national research programs. The SMIL management entity along with our community of university research teams are supporting returning these young career scientists. As an example, Dr. Ousmane Seyni and Dr. Moustapha Moussa (Niger) are acting as the Principal Investigators and Co-PIs on several USAID funded proposals to further develop sorghum forage and seed systems which was facilitated by the SMIL management entity. Dr. Elizabeth Diatta benefited from additional leadership and mentorship under the AWARD program because of the program's linkages. Three long-term Ph.D. female candidates are commencing their programs of study in US universities. Short-term trainings have continued despite the challenges of COVID-19 and the political and security risks in West Africa, Ethiopia, and Haiti.

**Short-term training**

In FY 2021, SMIL facilitated the short-term training of 887 individuals across 19 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 887 trainees, producers made up the largest group with 469 people trained, followed by 124 civil society members (predominantly researchers and students), 118 people in private sector firms, and 67 people in government. Of the total trainees, 446 were female and 441 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 2021 (Phase-II)***

| Country of Training | Purpose of Training | Who was trained | Number trained | | |
|---|---|---|---|---|---|
| | | | M | F | Total |
| Senegal | National Coordination Workshop of Feed the Future innovation laboratories | Producers | 36 | 25 | 61 |
| Niger | Seed production, soil management, IMP and seed ball technology have been done in May | Producers, Private Sector | 40 | 25 | 65 |
| Senegal | Exchange visit with ICRISAT's pearl millet breeding program | Government | 1 | 1 | 2 |
| Senegal | Workshop on pearl millet trials establishment, monitoring and phenotyping | Government | 10 | 5 | 15 |
| Burkina Faso | Training of farmers on seeds production skills | Producers | 98 | 9 | 107 |
| Niger | Hands-on methods of tissue collection and genotyping: example of sorghum RILs | Civil Society | 3 | 2 | 5 |
| Senegal | Analysis of protein digestibility in sorghum | Civil Society | 0 | 1 | 1 |
| Niger | End of season monitoring meeting on seed ball technology | Civil Society | 56 | 6 | 65 |
| Niger | Students training on proposal development | Civil Society | 6 | 1 | 7 |
| Niger | Training new farmers on seed ball technology in the Sahel | Producers, Private Sector | 42 | 10 | 52 |

| Country of Training | Purpose of Training | Who was trained | Number trained | | |
|---|---|---|---|---|---|
| | | | M | F | Total |
| Senegal | National Coordination Workshop of Feed the Future innovation laboratories | Producers | 36 | 25 | 61 |
| **Country of Training** | **Purpose of Training** | **Who was trained** | **Number trained** | | |
| | | | **M** | **F** | **Total** |
| Niger | Training on Awareness of Risks and Implications Associated with COVID-19 Pandemic using FAO prevention and guidelines directives | Producers, Private Sector | 33 | 105 | 138 |
| Niger | Training on digital data collection application was introduced to lead women update with their inputs, and a preliminary testing and simulation exercise of data collection at village sites, | Civil Society | 10 | 26 | 36 |
| Niger | Training on Dakoua (Millet-Peanut Snack like food) and Millet Degue processing at New Rural Spokes | Civil Society | 17 | 36 | 53 |
| Niger | Training of rural women grain processors on COVID-19- Awareness/and prevention and practices of hygiene when making innovative millet fortified flours for children at villages sites Food Innovation Centers in Niger | Producers, Private Sector, Civil Society | 10 | 64 | 74 |
| Niger | Backstopping of Emerging Youth and Women Processors Entrepreneurs to process and Market Grain Based Food During Ramadan 2021 | Private Sector | 5 | 22 | 27 |
| Niger | Capacity building training on digital application for data collection on market and nutrition components at villages level using smartphones | Producers, Private Sector, Civil Society | 8 | 29 | 37 |
| Senegal | Training on good practices for economic couscous | Civil Society | 10 | 40 | 50 |
| Senegal | Training on good practices on hygiene and fabrication in Saint Louis | Private Sector | 15 | 35 | 50 |
| Ethiopia | Hybrid Sorghum Seed Production | Government | 41 | 4 | 45 |

**Long-term training**
In FY 2021, the Sorghum and Millet Innovation Lab saw the remaining long-term training programs initiated in phase-I come to an end. This fiscal year saw the graduation for five long-term trainees, and 10 long-term trainees started their program during phase-II, bringing the total to 90 long-term trainees during phase-I and phase-II combined.

Among those 90 trainees, 62 are male and 28 are female. The group also represents a variety of degree levels with 3 agricultural engineers, 6 Bachelor's degrees, 38 Master's degrees, 39 Ph.D.'s and 4 post-docs.

***Table 2 Long-term trainees supported by the Sorghum and Millet Innovation Lab – FY 2021 (Phase-I & Phase-II)***

| 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 enterprise | 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 | Yes | 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 |

| Trainee Number | Sex | University | Degree | Major | Graduation date | Degree granted? | Home Country |
|---|---|---|---|---|---|---|---|
| 12 | Male | Haramaya University | Ph.D. | Plant pathology/breeding | Oct-17 | Yes - now pursuing Ph.D. at Haramaya University | 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 |

| Trainee Number | Sex | University | Degree | Major | Graduation date | Degree granted? | Home Country |
|---|---|---|---|---|---|---|---|
| 26 | Male | University of Thies | Master's | Agricultural engineering | Apr-17 | Yes | Senegal |
| 27 | Male | Universite de Thies | Master's | Agricultural Economics | Apr-17 | 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 enterprise | 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 | United States |

| Trainee Number | Sex | University | Degree | Major | Graduation date | Degree granted? | Home Country |
|---|---|---|---|---|---|---|---|
| | | | | | | U.S. Peace Corps in the Philippines | |
| 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 | May-19 | Yes - now pursuing Ph.D. at Purdue University | China |
| 39 | Male | Purdue University | Ph.D. | Plant pathology | Dec-20 | Yes | Ethiopia |
| 40 | Male | Kansas State University | Ph.D. | Plant breeding and genetics | Dec-19 | Yes | Ethiopia |
| 41 | Male | Kansas State University | Ph.D. | Plant pathology/breeding | Dec-20 | Yes | 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 | Post-doctoral studies | Plant breeding and pathology | May-21 | Yes | 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 | Yes | 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 | Yes | Niger |
| 50 | Female | Kansas State University | Ph.D. | Agronomy (Plant Breeding & Genetics) | May-20 | Yes | Niger |
| 51 | Male | Purdue University | Ph.D. | Food Science | Dec-19 | Yes - working at INRAN | Niger |
| 52 | Male | West African | Ph.D. | Plant Breeding | May-19 | Yes - working at INRAN | Niger |

| Trainee Number | Sex | University | Degree | Major | Graduation date | Degree granted? | Home Country |
|---|---|---|---|---|---|---|---|
| | | Center for Crop Improvement | | | | | |
| 53 | Female | University of Hohenheim | Master's | Agronomy/Soil science | Feb-19 | Yes | Niger |
| 54 | Male | University of Hohenheim | Post-doctoral studies | Agriculture | Sep-18 | Yes | 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 | Sep-23 | 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 | Yes | 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 | Uganda |

| Trainee Number | Sex | University | Degree | Major | Graduation date | Degree granted? | Home Country |
|---|---|---|---|---|---|---|---|
| | | | | | | University in 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 | Yes | USA |
| 68 | Male | Purdue University | Post-doctoral studies | Plant Genetics | Jun-17 | Yes | Nigeria |
| 69 | Male | University of Tillaberi | Master's | Plant Pathology/Plant Breeding | May-21 | Yes - intern at the National Institute of Agricultural Research of Niger | Niger |
| 70 | Male | Universite Abdou Moumouni Niamey | Ph.D. | Crop Physiology | May-23 | Yes – now pursuing Ph.D. at Universite Abdou Moumouni Niamey | Niger |
| 71 | Male | Universite Abdou Moumouni Niamey | Ph.D. | Crop Physiology | May-23 | Yes - now pursuing Ph.D. at Universite Abdou Moumouni Niamey | Niger |
| 72 | Female | Colorado State University | Ph.D. | Plant Breeding and genetics | Jun-23 | No | Senegal |
| 73 | Female | University Cheikh Anta Diop | Master's | Plant and microbial biotechnology | Oct-20 | Yes | Senegal |
| 74 | Male | University of Hohenheim | Master's | Agritropics | Jul-20 | Yes | United States |
| 75 | Male | University of Tillaberi | Master's | Food Science and Nutrition | Dec-22 | No | Niger |
| 76 | Male | Cheikh Anta Diop University | Ph.D. | Food Science and Technology | Dec-22 | No | Senegal |
| 77 | Male | Cheikh Anta Diop University | Ph.D. | Food Science and Technology | May-23 | No | Senegal |
| 78 | Male | Cheikh Anta Diop University | Ph.D. | Food Science and Nutrition | May-23 | No | Senegal |
| 79 | Male | Cheikh Anta Diop University | Master's | Plant and microbial biotechnology | Oct-20 | Yes | Senegal |
| 80 | Male | Ambo University, | Ph.D. | Plant Pathology | Sep-22 | No | Ethiopia |

| Trainee Number | Sex | University | Degree | Major | Graduation date | Degree granted? | Home Country |
|---|---|---|---|---|---|---|---|
| | | EIAR, Assosa Research center | | | | | |
| 81 | Male | University of Hohenheim | Master's | Agricultural Engineering | Aug-20 | Yes | Germany |
| 82 | Female | University of Niamey | Master's | Food Science and Nutrition | Dec-22 | No | Niger |
| 83 | Male | Haramaya University | Master's | Plant Breeding | Jul-22 | No | Ethiopia |
| 84 | Male | Mekelle University | Ph.D. | Plant Breeding | Jul-23 | No | Ethiopia |
| 85 | Female | Kansas State University | Ph.D. | Agricultural Economics | Jul-25 | No | Ethiopia |
| 86 | Female | Texas A&M University | Ph.D. | Plant Pathology and Microbiology | Jul-23 | No | Senegal |
| 87 | Male | University of Hohenheim | Post-doctoral Studies | Rural Sociology | Dec-22 | No | Ghana |
| 88 | Male | Ecole Nationale Supérieure d'Agricultu re | Engineer | Agricultural Engineering | Jul-21 | No | Senegal |
| 89 | Male | Ethiopia Institute of Agricultural Research (EIAR) | Master's | Plant Breeding | Jul-22 | No | Ethiopia |
| 90 | Female | National Institute of Agricultural Research of Niger (INRAN) | Bachelor's | Agriculture | May-24 | No | Niger |

**Institutional development**
Investments over the first and second phases of the program by the management entity and several SMIL projects have resulted in the formation of new institutional networks to reinforce research capacity. In West Africa, the SAWAGEN project leverages the expertise of scientists located in five countries of West Africa. Rather than reinforcing scientific capacity in each West African nation to focus on all the stresses and objectives within each country, the network promotes regional cooperation on varietal development. The regional cooperative model allows national program scientists to specialize in the development of traits that are of the highest importance to their nation while relying upon colleagues in other countries to do the same for other traits. Being part of a network allows one nation to draw upon the scientific advances of another so that pyramiding of traits becomes less time intensive. Each NARI scientist is pursuing trait development for which she or he has a comparative advantage and where a stressor has greater impact,

for example anthracnose in northern Togo or *Striga* in Niger. This permits scientists to focus, rather than spread their scarce resources, thereby developing deeper experience and expertise. Being part of a network where expectations of neighboring scientists are high creates "peer pressure" that encourages excellence and enhances of germplasm and traits. The network approach is far more cost- and time-effective than developing expertise for every single stressor in each country of the region, as presented in Figure 3.

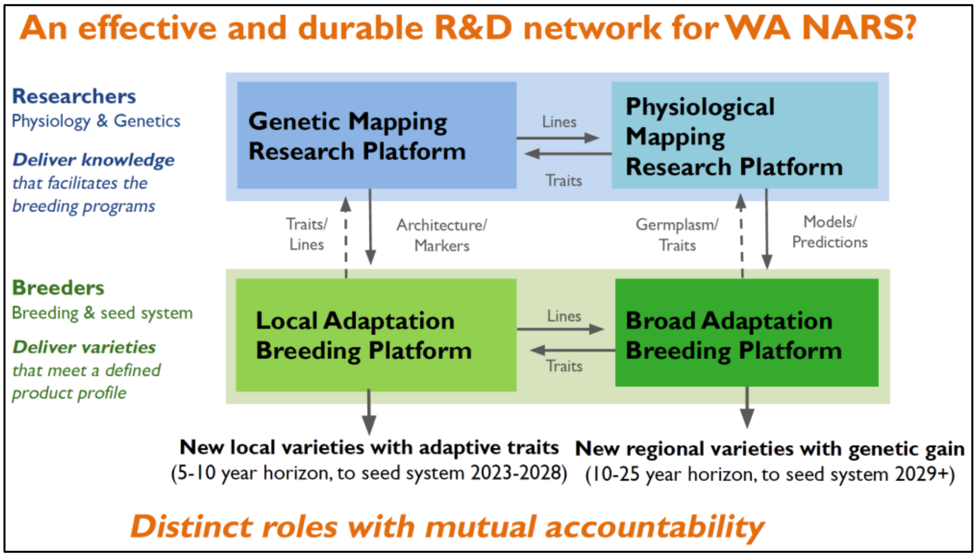



***Figure 3 R&D network for WA NARS from Morris project proposal***

SMIL sponsored training for the plant breeding team in West Africa to attend the Gender-Responsive Researchers Equipped for Agricultural Transformation (GREAT) training provided the team with key knowledge, principles, and tools to strengthen their breeding programs. Key outcomes have been realized back in country due to organizational leadership and enabling environment of our national partners. Specifically, the commitment by ISRA to their own internal Inclusiveness, Diversity, Equality, and Autonomization – IDEA policy statement that is guiding better document of which one element states "IDEA aims to promote: The inclusion of young people and women in programs and projects, as actors, beneficiaries, users and users of research results."

A similar approach to the pearl millet West Africa breeding network is being developed based on the success of the decentralized sorghum breeding network. The Genetic Enhancement of Pearl Millet for Yield, Biotic and Abiotic Stress Tolerance in West Africa (GENMIL) research project led by Dr. Ndjido Kane (Director of CERAAS) is supporting this regional local institutional capacity strengthening based within the existing NARS structure / teams.

We have also developed a similar, albeit smaller, network to test the hypothesis that Haiti, and other small countries like Haiti, can benefit from genomics-enabled breeding. Many argue that this is difficult given the capital-intensive nature of genomics, but this opinion largely rests on the "go it alone" proposition that national expertise is needed in all the elements of genomics and breeding programs. The Feed the Future Innovation Lab for Genomics-enabled Breeding, administered by the Sorghum and Millet Innovation Lab, challenged this hypothesis by breaking the process into tasks and distributing these tasks to different collaborators. In the case of Haiti, Quisquenya University and CHIBAS took responsibility for high quality phenotyping of sorghum germplasm assembled from many global sources to identify susceptible and resistant line against the sugarcane aphid. Cornell University developed the tools to capture DNA from these materials and processes for genomic analysis. Kansas State University was charged with bioinformatic analysis. This process facilitated the rapid cycling of testing and evaluation to identify the loci of the sugarcane aphid resistance genes and introgression into highly productive sorghum varieties in Haiti. Small countries can indeed benefit from genomics-enabled breeding especially when part of a cost-effective team.

The COVID-19 global environment allowed the SMIL program network to learn and adapt. Videoconferencing was largely productive despite intermittent outages of service, and we are using this learning to institutionalize distance collaboration much in the same manner that synchronous distance learning is embraced by educational systems. This is being integrated into our long-term communication strategy.

## Innovation Transfer and Scaling Partnerships

The Sorghum and Millet Innovation Lab (SMIL) continues to support the development of a sustainable pipeline of short-, medium- and long-term technology options in close partnership with our end-user clients and national programs. Our global network is engaged in a "first and last mile" approach where partnerships with end-users are developed at the inception of our technology product profiles. This supports and ensures that the "last mile" uptake by public or private sector is addressed at the onset to avoid discontinuity.

Delivery and scaling of improved seed technologies is a key activity for SMIL and our national partners. Developing and building on past investment in seed systems, the SMIL management entity will be providing strategic support for seed system meetings. Utilizing the existing seed system relationships along the seed value chain, our plan is to organize one day meetings to further document gaps, challenges, actual demand, and further organization of the field demonstrations of both off- and on- season plots with public and private seed system actors. Future product outputs and timelines that our national breeding teams are developing will also be presented at these joint meetings.

The SMIL continues to develop formal partnerships with other organizations bidding on USAID development funds as a mechanism to strengthen the connectivity between our in-country research / technology network and other USAID development program investments that can benefit from sorghum and millet value chain technologies.

Below is a summary list and description of the Phase 1 - 4 technologies.

***Phase 4 technologies (demonstrated uptake by public/private sector)***

### *1. Technology: Hybrids for commercial sorghum seed industry*

*Category:* Plant and Animal Improvement Research
*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), Regional Seed Enterprise (RSE), and private farms have been developed to support seed multiplication.
*Steps taken:* Approximately 30 hectares of hybrid seed was multiplied by a private seed producer in Amhara region.
*Target country:* Ethiopia

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

*Category:* Production Systems Research
*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

*Steps taken:* Discuss with donors and USAID value chain projects to support the dissemination.
*Target countries:* Senegal and Niger

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

*Category:* Production Systems Research
*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
*Steps taken:* Further sociological studies were carried out to better understand the farmer-to-farmer technology adoption mechanisms, number x type of training, extension support, etc. Initial investigations of the potential to apply this technology to sorghum production.
*Target countries:* Senegal and Niger

### 4. Technology: Registered germplasm with sugarcane aphid resistance for global use

*Category:* Production Systems Research
*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
*Steps taken:* Further sociological studies were carried out to better understand the farmer-to-farmer technology adoption mechanisms, number x type of training, extension support, etc. Initial investigations of the potential to apply this technology to sorghum production.
*Target countries:* Senegal and Niger

### 5. Technology: Improved sorghum variety

*Category: Plant and Animal Improvement Research*
*Area of inquiry: Genetic Enhancement*
*Description: An improved sorghum variety named Merera (ETSL 101371 (Acc. 212642)) has been officially released in Ethiopia with increased yield and disease-resistant characteristics.*
*Partnerships made: Oromia Ag. Research Institute, Bako Research Center, EIAR, and the National Research and Extension System (NARES)*
*Steps taken: Seed multiplication of this registered variety has been accomplished. Farmer plot trials / demonstrations completed and a large media publicity in vernacular radio and news has been organized in partnership with the regional government.*
*Target country: Ethiopia*

## Phase 3 technologies (made available for transfer)

### 1. Technology: Extruded sorghum- and millet-based food products

*Category:* Production Systems Research

*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, Green Yelda, CRS, and an Italian NGOs called ACRA interested in scaling up of the Innovation hubs in rural areas
*Steps taken:* Continue testing on the products for nutrient delivery efficiency as well as product consumer feedback.
*Target countries:* Senegal and Niger

## *Phase 2 technologies (under field testing)*

### 1. *Technology: Seed ball fabrication mechanization for men with mediocre investment capital*

*Category:* Production Systems Research
*Area of inquiry:* Production systems management
*Description:* Men will only invest in seed ball 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 seed balls per hour at medium (in the local sense) investment costs.
*Partnerships made:* Fleischle GBR, Vaihingen Enz, Germany
*Steps taken:* The mechanization 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 seed ball production are underway: **https://seedtheglobe.com/en/platform.html**.
*Target country:* Niger

### 2. *Technology: Seed ball fabrication mechanization for women with low investment capital*

*Category:* Production Systems Research
*Area of inquiry:* Production systems management
*Description:* The technology is based on an easy-to-construct frame that produces about 80 seed balls in one batch. It is designed particularly for women with low investment capital that need to sow more than a home garden surface.
*Partnerships made:* Fleischle GBR, Vaihingen Enz, Germany
*Steps taken:* The mechanization 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 to increase productivity. The presented tool did not sufficiently reduce working time needed in comparison to hand-made seed balls.
*Target country:* Niger

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

*Category:* Plant and Animal Improvement Research
*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 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
*Steps taken:* 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: Improved endosperm sorghum for protein quality and processing functionality***

*Category:* Production Systems Research
*Area of inquiry:* Added-value products and markets
*Description:* New sorghum hybrids under development combine high protein digestibility (HPD) mutation with waxy and heterowaxy (WX/HX) starch traits in hard endosperm for various food applications due to superior functionality and improved protein nutritional quality.
*Partnerships made:* Hawassa University, Texas A&M University, Ethiopian Institute of Agricultural Research
*Steps taken:* Field trials are being organized by EIAR for the future advancement of this hybrid for national registration. Production of 200-300 kg of grain to allow Hawassa University to continue food science testing and R&D of the grain for application in the Ethiopia food product market.

### Phase I technologies (under research)

1. ***Technology: PCR-based tag system to accelerate sorghum breeding for disease resistance***

*Category:* Plant and Animal Improvement Research
*Area of inquiry:* Genetic Enhancement
*Description:* Develop a simple and efficient scored PCR-based tag system that will greatly speed breeding of disease-resistant sorghum cultivars, even in the absence of the pathogen.
*Partnerships made:* ISRA, INRAN
*Steps taken:* Development of the PCR-based tag system, training, and the arrival of Coumba Fall to TAMU for her Ph.D. training.
*Target country:* Senegal and Niger

2. ***Technology: Striga resistance, stay-green, and drought tolerance alleles development and deployment***

*Category:* Plant and Animal Improvement Research
*Area of inquiry:* Genetic Enhancement
*Description:* Develop *Striga* resistance, stay-green, and drought tolerance alleles for smallholder demand driven product profiles in West Africa.
*Partnerships made:* ISRA, INRAN, INERA, ITRA
Senegal - Farmers organizations (RESOPP, ASPRODEB–Kaffrine and Kaolack, BAMTARE–Tambacounda); Food processors (women and NGO–KARITAS–Tambacounda); Industrials (Mamelle Jaboot, FNBS) and other research instituts (ITA)
Niger - Seeds companies including Hallal, Fusaa
Burkina Faso - FEPAB in the north-west, UGCPA in the south-west, AMSP in the east and G-NAAM in the north

Togo - OP Todlman grouping several farmers' organizations / location: Takpamba, Timbou, Goulougoushi, Naki-Est, Mandouri
*Steps taken:* Initial farmer field level trials and feedback on these materials to support the near-term registration and seed distribution.
*Target countries:* Senegal, Niger, Burkina Faso, Togo, (West Africa)

## 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 in-country partners have continued to ensure that the research activities being funded comply with the national and USAID environmental compliance requirements as stated in the initial environmental evaluation.

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

The open data management plan has continued to be implemented and the SMIL management entity has assisted each research project in the ongoing delivery of datasets into Harvard Dataverse and/or other relevant scientific databases that support their research. Each awardee and sub-awardee are submitting the link of each planned and in-progress dataset in our data collection/reporting system, the SMIL resource and reporting hub. In addition to the dataset, the data package includes metadata and other supporting documents; including codebooks that describe columns in the dataset, questionnaires used to collect data, informed consent forms, reports, and any other contextual documents. Research teams are ensuring that datasets are cleaned, and all personally identifiable information is excluded. Links to all data repositories are registered on the USAID DDL.

## Governance and Management Entity Activity

**COVID-19 response and project planning**
The program has continued to adapt to the COVID-19 situation. All essential program implementation activities and essential coordination meetings with external partners were successfully carried out. The SMIL annual program review meeting was held again through a remote online platform over the course of 4 days. This structure provided ample time for project presentations, discussion, and internal review by the external advisory board.  In Niger the entire research team, women entrepreneurs and seed company end-users gathered in a coordinated manner in Niamey the capital.  This allowed better internet connectivity and inclusion of our end-user team members.  During the fiscal implementation year, all project activities with downstream clients and other field activities were implemented using necessary safety protocols and travel authorizations.

The Management Entity also traveled to the hosting universities for face-to-face meetings with principal investigators and their teams.  During the 2021 fiscal year, visits were made to Texas A&M University, Colorado State University as well as Purdue University in September and October 2021.  In addition, the ME also visited the Western Kansas Agricultural Research Station to interact with the pearl millet breeding team and director of the Western Kansas Research and Extension Centers.  These visits were widely appreciated and provided excellent environments for considering research findings, project implementation planning, downstream scaling partnerships and interaction with future SMIL/USAID support scientists. These meetings also provided time and space to consider of the much longer-term view of key demands and needed developments along the sorghum and pearl millet value chains in the next five to ten years. The ME was also able to capture key video interviews to strengthen our communication initiatives.

## Other Topics

**Communications project**
With guidance from our SMIL External Advisory Board (EAB) and our USAID Agreement Officer Representative (AOR), the SMIL management entity developed a specific communications project leveraging in the Kansas State University Department of Communications and Agricultural Education linked with other private media and marketing services. The overall goal of the SMIL communications project is to "celebrate the success" of the SMIL/USAID investment in sorghum and millet, cultivate enthusiasm for future endeavors, and encourage the next generation of researchers/scientists in international development.

The SMIL communications project will consist of restructuring the SMIL website, project personnel interviews and research images, collection and display of video content, quarterly newsletters, success stories, increased social media engagement, targeted print documents, and other relevant media forms that support the key goals of the project. Information gathering and plans are being made to form a SMIL student and young career professional alumni platform to strengthen research collaboration and opportunities as well as networking.

**Economic Impact Assessment**
Economic assessment of SMIL and SMIL-associated policy issues has produced new publications, submissions, and novel insight into research priority setting. Research shows that enhancing agricultural productivity growth is a key step to improving competitiveness and eradicating poverty rural areas in developing countries. While the Comprehensive African Agricultural Development Program (CAADP) recommended increased public spending in agriculture to induce productivity growth, the extent to which expenditures affect food productivity remains an empirical question. To address this concern and provide policymakers with quantitative evidence of the return to investment, we assessed the effect of two government-spending measures: Agriculture Budget Share (BS) and Research Share of Agricultural GDP (RS) on agriculture total factor productivity growth (TFPG) in Africa. We used a panel fixed-effect estimator to control for the country-specific characteristics of twenty-eight African economies from 1991–2012. We found a marginal impact of 6.77% for RS on TFPG after seven years. However, the cumulative marginal impact of BS on TFPG is estimated at 7.21% over the eight years following the budget allocation. Our findings suggest that a BS of 14% and a RS of 15% are required for a country to double its TFPG in the following eight years. Therefore, additional, and continuous investment in research and development is required for a significant productivity growth, especially in Sub-Saharan Africa.

At the microeconomic level, the impact of farm input subsidy vouchers on household food caloric production was assessed. We used pooled cross-sectional household data from the 2010, 2013, 2016 and 2019 Malawian Living Standards Measurement Study and Integrated Survey on Agriculture (LSMS-ISA) to fit a two-stage panel fixed effect model under an endogenous treatment assignment setting. Our findings suggest that benefits from an existing input coupon positively affect household food calories production. Also, we found the flexible coupon traded for either compound fertilizer, urea, or improved maize seed to have the greatest impact. Furthermore, larger farm holders and coupons receivers in 2019 had the highest coupon impact on caloric production. Expanding subsidy programs could result in improved food availability for farming households.

In another paper under review, we investigate urban consumer preference for a time-saving food attribute in Niger motivated by a Becker-type time allocation model. Using an experimental method that combines hedonic testing and a choice experiment, we highlight that not all consumers are favorable in saving cooking time. These results confirm our theoretical prediction on the ambiguity of the time-saving effect on consumer behavior. For the time-conscious consumer segment, about 38% of all Nigerien urban consumers, we estimate the endogenous shadow wage consumers are willing to pay to save household cooking time at 290 FCFA per hour. We estimated the total annual market value of extrusion to be about US$240,733 for 25% market penetration to $962,931 at full penetration for the time-saving consumer group.

Future research is examining the willingness to pay and demand for improved sorghum varieties in Ethiopia. In the first half of FY2022, a report will be released on the potential impact of pearl millet seed balls based on several years of agronomic and economic information. Another paper in review describes the pattern of expenditures in the Collaborative Research Support Program and Innovation Labs from 1978 to 2018 and compares it against published studies that have estimated net benefits. This paper shows a high ratio of benefits to U.S. investment over the forty-year period.

*Capacity building*

Individuals trained under this project include:

| | | | |
|---|---|---|---|
| 85 | Kansas State University | Ph.D. | Agricultural Economics |

*Presentations and publications*

M. Hodjo, T. Dalton, T. Nakelse, R. N. Acharya, and D. Blayney. "From coupon to calories: Assessing input coupon impact on household food calories production." World Development Perspectives, Volume 22, 2021. https://doi.org/10.1016/j.wdp.2021.100316.

M. Hodjo, Dalton, T.J. and Nakelse, T. "Does Public Spending Trigger Agricultural Productivity Growth in Africa?" *Forthcoming: Journal of African Development.*

Nakelse, T., T.J. Dalton, and M. Hodjo. "Time isn't Money: Shadow Wage Derivation from Hedonic Food Valuation." *In review.*

Dalton, T. and K. Fuglie. "Costs, Benefits and Welfare Implications of USAID Investment in Agricultural Research through U.S. Universities." *In review.*

# Future Directions

**Strategic Planning for the Future**

Our Theory of Change (ToC), embedded in the Sorghum and Millet Innovation Lab's activities, is based on a "bottom up" approach of identification of needs and priorities derived from stakeholders along the sorghum and millet value chains. National documented priorities were a basis for the competitive call for proposals and funding of innovative research projects to address national identified needs. The management entity (ME) has initiated discussions with our target country leadership to reconsider changes in their national needs which will be further explored and documented. One key output will be a product profile review process by the national breeding programs to further align with the evolution of end-users and national needs.

The potential for regional spillovers of research networks and much larger regional technology dissemination is underway. Opportunities in Republic of Sudan, Republic of South Sudan, and Uganda are being explored particularly along the sorghum value chain.

The SMIL ME will be hosting a West Africa pathology seminar titled, "Prevalence and Incidence of Foliar and Panicle Diseases of Sorghum across Production Fields in Niger and Senegal, West Africa". Specific disease pattern results found from farmer field site surveys under the research project "Enabling Marker Assisted Selection for Sorghum Disease Resistance in Senegal and Niger" led by Dr. Magill at Texas A&M University, will be further disseminated and discussed with our West and East Africa and Haiti teams.

The Food Science and Technology Department at Hawassa University has been developing sorghum-based processing technologies, recipes, and food products and as a partner in the project "Advancing Improved Functionality and Protein Quality Sorghum Hybrids for Food Applications in Ethiopia" led by Dr. Awika at Texas A&M University. The team has consolidated information of these technologies and a list of current SME private sector companies using these technologies. An SMIL ME facilitated meeting will be organized to develop larger technology showcasing and private sector engagement plans.

Product profile concepts, delivery and actual sustainable uptake of improved seed technology is a key concern for SMIL and our national partners. Developing and building on past investment in seed systems, the SMIL management entity will organize seed system meetings in our target countries along the sorghum and millet value chains. Utilizing the existing and new seed system relationships, we will facilitate joint meetings to further document gaps, challenges, actual demand, and further schedule field demonstrations for public / private seed system actors. Future product concepts and outputs with timelines will also be presented in these joint meetings by the national breeding teams.

The national sorghum teams in Niger and Ethiopia are acting as principal investigators and Co-PI in the following competitive proposal submissions to the Livestock Systems Innovation Lab (LSIL). If selected, these teams will further develop sorghum forage research and technologies to respond to livestock feed / forage demand in West and East Africa.

- Establishing Networks, Growing Adoption, and Guiding market development for forage technologies in Ethiopia (ENGAGE)
  Reach Grant / 3 Years / $750,000
- Enhancing the productivity of small ruminants and poultry to reduce malnutrition and poverty in Niger
  Reach Grant / 3 Years / $750,000
- Sustainable scaling of dedicated forage sorghums and dual-purpose sorghums to increase small ruminant production in Niger through a private sector and community-based farmer organization seed production network
  Focus Grant / 1.5 Years / $150,000

# Appendices

### *Appendix A – 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

| | |
|---|---|
| FY21 Funding Released: | $219,830.00 |
| Total Funding Released: | $564,870.00 |
| Overall Project Budget: | $929,658.00 |

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**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

| | |
|---|---|
| FY21 Funding Released: | $140,946.00 |
| Total Funding Released: | $348,185.00 |
| Overall Project Budget: | $472,500.00 |

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**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

| | |
|---|---|
| FY21 Funding Released: | $130,658.00 |
| Total Funding Released: | $360,238.00 |
| Overall Project Budget: | $523,567.00 |

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

| | |
|---|---|
| FY21 Funding Released: | $187,496.00 |
| Total Funding Released: | $542,677.00 |
| 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 |

| | |
|---|---|
| FY21 Funding Released: | $83,793.00 |
| Total Funding Released: | $181,004.00 |
| Overall Project Budget: | $371,843.00 |

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

| | |
|---|---|
| FY21 Funding Released: | $40,055.00 |
| Total Funding Released: | $99,132.00 |
| Overall Project Budget: | $155,991.00 |

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

| | CSU | KSU | Total |
|---|---|---|---|
| FY21 Funding Released: | $73,776.00 | $4,744.00 | $78,520.00 |
| Total Funding Released: | $73,776.00 | $166,219.00 | $239,985.00 |
| Overall Project Budget: | $214,847.00 | $166,219.00 | $381,066.00 |

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| | | |
|---|---|---|
| **Title:** | Genetic Enhancement of Pearl Millet for Yield, Biotic and Abiotic Stress Tolerance in West Africa (GENMIL) | |
| **Award:** | CSU – Geoff Morris | |
| **Project Dates:** | 04/01/19 | 07/21/23 |

| | KSU-Hays | CSU | Total |
|---|---|---|---|
| FY21 Funding Released: | $0.00 | $47,699.00 | $47,699.00 |
| Total Funding Released: | $83,839.00 | $47,699.00 | $131,538.00 |
| Overall Project Budget: | $83,839.00 | $216,888.00 | $300,727.00 |

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**Title:** Durable adaptation to aphid and drought for smallholder sorghum in the Americas
**Award:** CSU – Geoff Morris
**Project Dates:** 10/01/20 07/21/23

FY21 Funding Released: $120,184.00
Total Funding Released: $120,184.00
Overall Project Budget: $595,930.00

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**Title:** Agricultural Economics Research un the Sorghum and Millet Innovation Lab
**Award:** KSU – Timothy Dalton
**Project Dates:** 12/01/20 07/21/23

FY21 Funding Released: $153,925.00
Total Funding Released: $153,925.00
Overall Project Budget: $286,333.00

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**Title:** Sorghum and Millet Innovation Lab Communications and Branding
**Award:** KSU – Susan Schiff
**Project Dates:** 07/01/21 07/21/23

FY21 Funding Released: $48,750.00
Total Funding Released: $48,750.00
Overall Project Budget: $48,750.00

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## *Appendix B – Success stories*

### Building Strong Sorghum in Ethiopia

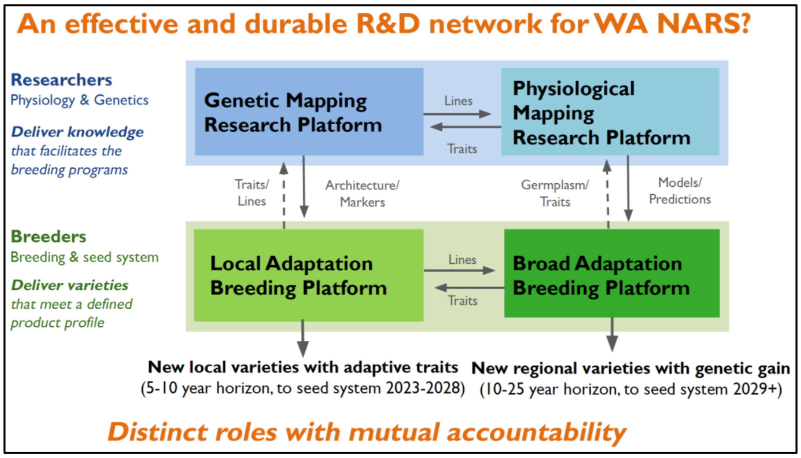
"In Ethiopia, close to 2 million hectares of sorghum are grown every year and sorghum is one of the top five crops which is deeply rooted in the dyadic culture. Droughts and disease are serious problems and sorghum is the last crop to fade," said Dr. Tesfaye Mengiste in an interview with Dr. Benjamin Kohl.

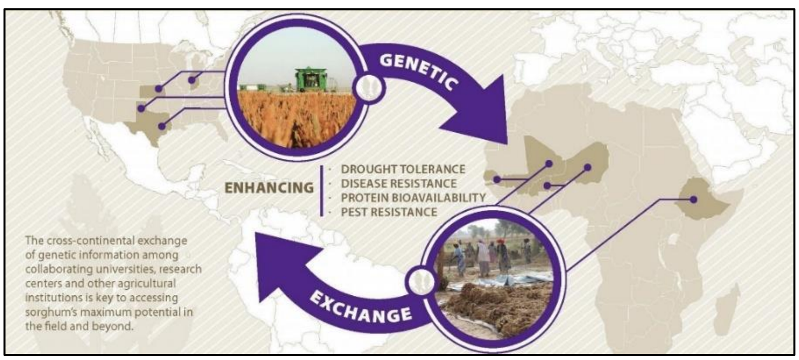
Dr. Mengiste's SMIL team works hard to produce sorghum that is resistant to fungal pathogens. Last year, Dr. Mengiste's team produced an improved red sorghum variety named "*Merera*" ETSL 101371 (Acc. 212642) for use by smallholder farmers. This year, the Merera sorghum has provided up to a 43.1% yield increase over standard checks and is adapted to rainfall areas of 1,100-1,200 (mm) at altitudes of 1,500 - 1,900 (masl). The Merera variety has proven to be resistant to anthracnose, which is caused by fungi in the genus *Colletotrichum*, a common group of plant pathogens that are responsible for diseases on many plant species.

Dr. Mengiste's team, along with Ethiopian Institute of Agricultural Research and the Oromia Agricultural Research Institute partnerships, made further progress with the demonstration and scaling up of the Merera variety and some were interviewed by regional news broadcast journalists. Demonstration and seed multiplication of the Merera variety is being conducted in five sorghum-growing districts of Western Ethiopia, on 40 farmers' fields. Farmers research groups, consisting of 15 farmers, were established at each of the smallest administrative farming units. This formalized group of farmers is highly engaged in development and popularization of Merera.

### Global Genomics-Enabled Breeding Networks

The SMIL/USAID investment to establish global genomics-enabled breeding networks is having both short- and long-term impacts. These networks are leveraging unique capacities to accelerate the response of our National Agricultural Research System (NARS) partners to address their national sorghum and millet plant breeding goals. These decentralized breeding networks based on the NARS, provide a platform where new waves of early career scientists can integrate their novel genomics tools and training into traditional breeding programs. Four decentralized, yet interdependent, platforms based on NARS capacity is in place in West Africa to provide sorghum breeders with a dynamic interface to respond to end-user trait demand and climate change adaptation. This network has strategically leveraged global genomics capacity with the in-country NARS traditional breeding program. This network has accelerated the pace of developing improved sorghum varieties as well as creating a pipeline for long-term product delivery.




A similar platform is being established along the pearl millet value chain through a research project led by Dr. Ndjido Kane (Director of CERAAS) "The Genetic Enhancement of pearl Millet for Yield, Biotic and Abiotic Stress Tolerance in West Africa (GENMIL)." This NARS-led platform will enhance material sharing, germplasm evaluation, and the development of a network of breeders with on-farm co-creation breeding processes.

In Haiti, our program has had remarkable success through the creation of a platform which pairs the genomics mapping and bioinformatics capacity of land grant university departments with a traditional small country breeding program. This has been the basis for unique discoveries and a product development capacity to respond to the emerging smallholder demands linked to sugarcane aphid pressure, climate adaptation and end-use requirements in Haiti. The SMIL/USAID support to establish this global genomics-enabled breeding network has resulted in global access to unique sugarcane aphid (SCA) resistant materials. This has benefited the US sorghum industry and a "no strings attached" private sector funding was provided by a US seed company to further the SCA science.

This Haiti experience is one example of the SMIL/USAID program's strategic support to cutting-edge research and a truly global genomics enabled breeding network that is accelerating genetic exchange for the benefit of our USAID target countries / regions. This has provided tangible global good and key spill-in benefits to US sorghum production.

**Pearl Millet Seed Balls to Sorghum Success**

Dr. Ludger Herrmann and his team introduced pearl millet seed balls to local farmers in the Maradi and Falwel regions of Niger. The seed ball technology is a simple and affordable seed-pelleting technique that uses locally available materials such as sand, loam, wood ash and seeds to enhance early crop establishment. pearl millet seed balls have proven to be a low-risk and high-yield technology that has been tested in thousands of field trials in Sahelian environments.

Seed balls were first developed to support pearl millet cropping. After seeing the 20-30% yield, farmers wanted the seed balls for their sorghum crops, too. In greenhouse trials for sorghum, the standard recipe had to be slightly changed to include a larger diameter with higher nutrient content. The transfer of the seed ball technology from pearl millet to sorghum cropping was a great success. The sorghum seed balls continue to be successfully tested in on-farm trials in the Falwel region of Niger.

Seed balls improve the pearl millet and sorghum-based farming systems in the Sahel at the very critical stage of germination and early crop growth. SMIL partner, McKnight Foundation, helped to fund seed ball technology training for two R4D projects: Women's Field and CATI-GAO. Women make up 90% of the 3,000 farmers who have tested the seed ball technology on their pearl millet and sorghum crops.