FEED THE FUTURE

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

INNOVATION LAB FOR FOOD PROCESSING AND POST-HARVEST HANDLING

# FIVE-YEAR FINAL REPORT

May 19, 2014 – May 18, 2019

USAID FROM THE AMERICAN PEOPLE

FEED THE FUTURE FPL FOOD PROCESSING LAB

PURDUE UNIVERSITY

**Feed the Future Innovation Laboratory for Food Processing and Post-Harvest Handling (FPL)**

**Five-Year Final Report**

**May 19, 2014 – May 18, 2019**

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**Front cover photos: (left to right)**

*Demonstration of a small extruder at ITA, Dakar, Senegal*
Photo credit: Julie Hancock, Purdue Univ.

*Traditional storage for maize in Velingara, Senegal*
Photo credit: Jonathan Bauchet, Purdue Univ.

**Back cover photos: (left to right; top to bottom):**

*FPL drying and storage resource table at workshop in Kenya*
Photo credit: Patrick Ketiem, KALRO

*Student trainees at the University of Eldoret Food Processing Training and Incubation Center*
Photo credit: Betty Bugusu, Purdue Univ.

*Ceremony for the extruder installation in Touba, Senegal*
Photo credit: Senegalese photographer

*Post Harvest Handling workshop in Senegal*
Photo credit: Jonathan Bauchet, Purdue Univ.

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# ACRONYMS

| | |
|---|---|
| ACRE | Agronomy Center for Research and Extension |
| CGIAR | Consortium of International Agricultural Research Centers |
| CLM | Cellule de Lutte Contre la Malnutrition (National Committee for Control of Malnutrition) |
| CIMMYT | International Maize and Wheat Improvement Center |
| CIP | International Potato Center |
| EMC/ERH | Equilibrium moisture content/equilibrium relative humidity |
| FPTIC | Food Processing and Training Incubation Center |
| FPL | Food Processing and Post-harvest Handling Innovation Lab |
| FtF | Feed the Future |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics |
| IFTC | International Food Technology Center |
| IITA | International Institute of Tropical Agriculture |
| IPIA | International Programs in Agriculture |
| ISRA | L'Institut Sénégalais de Recherches Agricoles |
| ITA | Institut de Technologie Alimentaire |
| JTI | JUA Technologies International LLC. |
| KALRO | Kenya Agricultural and Livestock Research Organization |
| KEBS | Kenya Bureau of Standards |
| NCSU | North Carolina State University |
| NGO | Non-governmental Organization |
| PHL | Post-Harvest Innovation Lab (at Kansas State University) |
| PICS | Purdue Improved Crop Storage |
| PIMA | Purdue Improved Moisture Assessment |
| POD | Picosolar crOp dryer |
| R&D | Research and development |
| RH | Relative humidity |
| SOPs | Standard Operating Procedures |
| SSA | Sub-Saharan Africa |
| USA | United States of America |
| USAID | United Stated Agency for International Development |
| USD | United States dollar |
| USDA-ARS | United States Department of Agriculture – Agriculture Research Service |
| WTP | Willingness to pay |

# EXECUTIVE SUMMARY

This report presents progress over the first five-year phase of the Feed the Future Innovation Laboratory for Food Processing and Post-Harvest Handling (May 19, 2014-May 18, 2019). The Food Processing Innovation Lab's (FPL) goal is to increase access to safe and nutritious foods along the value chains by improving the drying and storage capacity of smallholder farmers and expanding market opportunities through diversified processed products that address quality in the market and nutritional needs. The program focuses on cereals and grain legume value chains in Kenya and Senegal. FPL targets locally available nutrient-rich value chains to enhance the nutrition of processed products. The major outcome for FPL is to develop and disseminate technologies, best-practices and other innovations that are replicable, cost-effective, scalable, and commercially viable for smallholder farmers, small-scale traders, food processors, and consumers in Kenya, Senegal, and other Feed the Future countries. Scaling-up technologies to create sustainable post-harvest value chains that promote resiliency among our target populations will be a focus in Phase II of FPL.

The two major focus areas of FPL, their overall objectives, and related specific accomplishments, are:

1. Drying and Storage: Improve drying and storage of cereals and grain legumes in Africa humid tropics:
   - Developed and moved toward commercializing the hygrometer as a low-cost moisture determination method
   - With a focus on low-cost grain drying technologies for smallholders, developed two types of solar dryers and a tray for solar drying
   - With a focus on preventing aflatoxin development in grains and oilseeds during hermetic bag storage, determined ≤13% as the optimum moisture content for safe storage
   - Through socio-economic assessment of grain drying and storage alternatives (for smallholder farmers, farmer associations, small-scale grain traders, and food processors), showed the importance of promoting the use of tarps and raised platforms for solar drying of maize, and the willingness of smallholder farmers to purchase hygrometers to assess moisture content of grain.
2. Processing and Nutrition: Drive the value chain through processing to increase commercialization and improve nutrition.
   - Assessed market demand and drivers for processed food products in Kenya and Senegal to provide direction for product development work; Results confirmed focus on instant (vs. conventional), fortified, whole-grain food products
   - Evaluated nutritional composition of plant materials and the micronutrient retention/ bioaccessibility in food products, and solar dried natural fortificants; Results determined which nutrient-dense plant materials to use as fortificants (especially carrot, baobab, and moringa)
   - Identified, developed, and refined food products and processes (especially instant, extruded, fortified with nutrient-dense plants) for cost effective, bioaccessible, and commercially relevant fortified millet and maize/sorghum products (for both rural and urban markets in Kenya and Senegal)
   - Began process to evaluate nutrition impact of program, specifically increasing iron bioavailability.

Both focus areas of FPL were involved in strengthening institutional and human capacities and in establishing and strengthening public-private partnerships to promote technology innovation and adoption. FPL funded (either fully or partially) the following: a) 27 students for long-term training; b) 27 project collaborators for short-term training; c) 12,840 farmers, traders, agricultural extension agents, and technicians for training on proper drying and storage practices/technologies; and d) 188 entrepreneurs, food processors, students, and youth for training on processing methods, natural fortification, and entrepreneurship.

# PROGRAM PARTNERS AND PERSONNEL

(Original personnel, with all changes indicated, and personnel added)

***Lead University:***

Purdue University

***Partner Organizations:***

| | |
|---|---|
| USA: | North Carolina A&T State University |
| | North Carolina State University |
| Kenya: | University of Eldoret |
| | International Maize and Wheat Improvement Center (CIMMYT), Kenya |
| | Kenya Agricultural Livestock Research Organization (KALRO) |
| Senegal: | Institut de Technologie Alimentaire (ITA) |
| | Institut Senegaliais de Recherches Agricoles (ISRA) |
| South Africa: | University of Pretoria |
| Company: | A to Z Textiles, Tanzania |
| | Bell Industries, Kenya |

***Leaders:***

Dr. Betty Bugusu, Dept. Food Science, and Purdue Univ. (Project Director 2014-18)
(Change: Was Director in 2014-18, then took a position on another USAID project)

Dr. Suzanne Nielsen, Prof., Dept. Food Science, Purdue Univ. (Deputy Director, 2014-18; Director, 2019)

Dr. Bruce Hamaker, Prof., Dept. Food Science, Co-Director of International Food Technology Center, Purdue Univ. (Team Leader for Processing & Nutrition)

Dr. James Lowenberg-DeBoer, Prof., Dept. Agricultural Economics, Assoc. Dean & Director, International Programs in Agriculture (IPIA), Purdue Univ. (Team Leader for Drying and Storage, 2014-17) (Retired from Purdue in 2017)

Dr. Jacob Ricker-Gilbert, Asst. Prof., Dept. Agricultural Economics, Purdue Univ. (Team Leader for Drying & Storage, 2017-19)

***Investigators and Collaborators – USA and Africa:***

***<u>USA</u>:***

Dr. Corinne Alexander, Assoc. Prof., Dept. Agricultural Economics, Purdue Univ. (Deceased, Jan. 2016)

Dr. Jonathan Bauchet, Asst. Prof., Dept. Consumer & Family Studies (Became involved in project after Corinne Alexander died)

Dr. Guibing Chen, Asst. Prof., North Carolina A&T State Univ. (Involved in project 2014-17)

Dr. Mario Ferruzzi, Prof., Dept. Food Science and Dept. Nutrition Science, Purdue Univ. [Moved to North Carolina State University (NCSU), but continued involvement]

Dr. Klein Ileleji, Prof., Dept. Agricultural & Biological Engineering, Purdue Univ.

Dr. Cheryl O'Brien, Asst. Prof., San Diego State Univ.

Dr. Arvind Raman, Asst. Dean, College of Engineering, Purdue Univ.

Dr. Richard Stroshine, Prof., Dept. Agricultural & Biological Engineering, Purdue Univ.

Dr. Charles Woloshuk, Prof., Dept. Botany & Plant Pathology, Purdue Univ.

***<u>Kenya</u>:***

Dr. Hugo De Groote, Principal Scientist, Agricultural Economics, CIMMYT, Nairobi, Kenya

Dr. Patrick Ketiem, Senior Research Officer, Climate Change/Agro-processing, KALRO, Centre, Njoro, Nakuru, Kenya
Dr. Violet K. Mugalavai, Prof. & Head, Dept. Family Consumer Sciences, Univ. Eldoret, Eldoret, Kenya
Mr. Bernard Munyua, Research Associate, Agricultural Economics, CIMMYT, Nairobi, Kenya
Dr. Augostino Onkware, Prof., Univ. Eldoret, Eldoret, Kenya

***Senegal:***
Dr. Cheikh Ndiaye, Lead PI, ITA, Dakar, Senegal
Dr. Djibril Traore, Nutrition Director, ITA, Dakar, Senegal
Mr. Fallou Sarr, Director of External Relations, ITA, Dakar, Senegal
Dr. Ibrahim Sarr, Head of Entomology Lab/Coordinator of the Natural Resources Management Program, ISRA, Dakar, Senegal
Dr. Moussa Sall, ISRA, Dakar, Senegal
Mr. Katim Toure, ISRA, Dakar, Senegal

***South Africa:***
Dr. Gyebi Duodu, Assoc. Prof., Dept. Food Science, Univ. of Pretoria, South Africa
Dr. Johanita Kruger, Faculty, Center of Nutrition, Dept. Nutrition, Univ. Pretoria, South Africa
Dr. John Taylor, Prof., Dept. Food Science, Univ. of Pretoria, South Africa
Dr. Henriëtte (Riette) de Kock, Assoc. Prof., Dept. Food Science, Univ. of Pretoria, South Africa

# PROGRAM OVERVIEW

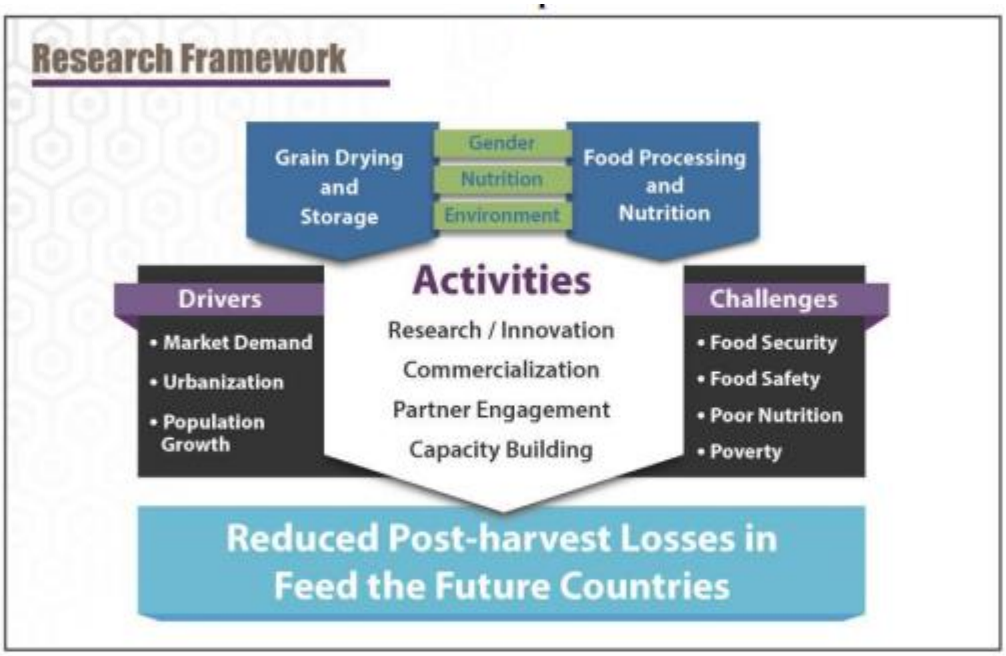
**Overview:**

Hunger, malnutrition, and poverty remain stubbornly persistent in many developing countries despite advances made in agriculture productivity in recent years. This is due in part to high food losses, especially after harvest. The project research supported and strengthened the postharvest segment of the value chain using a market-led approach to overcome constraints that create food losses in targeted Feed the Future (FtF) countries. This was achieved through development and use of on-farm drying and storage technologies coupled with food processing innovations and mechanisms of dissemination that linked farmers to markets. The project focused on cereal (maize, sorghum, millet) value chains in Kenya and Senegal with two core research components: 1) grain drying and storage, and 2) food processing and nutrition. Nutrition was a major component of the project. The cross-cutting issues of gender and environment will be taken into account at all stages of the project cycle, from baseline assessment and analysis through research implementation, monitoring, and evaluation.

**Project Goal:**

Consistent with FtF priorities, the overall goal of the project was to develop sustainable, market-driven value chains that reduce food losses, improve food and nutrition security, and contribute to economic growth for farmers in Kenya and Senegal. The models can then be scaled up with modifications to other FtF countries.

**Research Framework:**




This figure represents the overall research framework with its two research components. 1) Grain Drying and Storage - Post-harvest grain losses in Africa most often occur due to poor drying after harvest, causing mold contamination, and insect infestation during storage. The activities will focus on developing affordable drying, moisture testing, and storage technologies for smallholder farmers especially in the humid tropical regions of sub-Saharan Africa. Doing so will increase availability of high quality grains and legumes for commodity markets and for further processing into value-added products. 2) Food Processing and Nutrition - These efforts aim to increase and diversify food processing and markets for cereal and legume products at the rural and urban levels, and to create a sustainable market-driven model for nutritionally-enhanced foods. Overall, these efforts will increase market opportunities and enhance farmer linkages to markets. Research activities will focus on improvement of existing technologies and products, as well as development of new ones. Through innovative mechanisms for dissemination, these activities will improve quality, safety, and nutritional options for consumers, leading to increased market opportunities for producers.

**Specific Objectives:**

1. Improve drying and storage of cereals and grain legumes in the humid tropics of Africa.
2. Drive the value chain through processing to increase commercialization and improve nutrition.
3. Strengthen institutional and human capacities among the actors along the value chains, with emphasis on gender sensitive approaches.
4. Establish and strengthen public-private partnerships to promote technology innovation and adoption

**Impact Pathway and Theory of Change:**

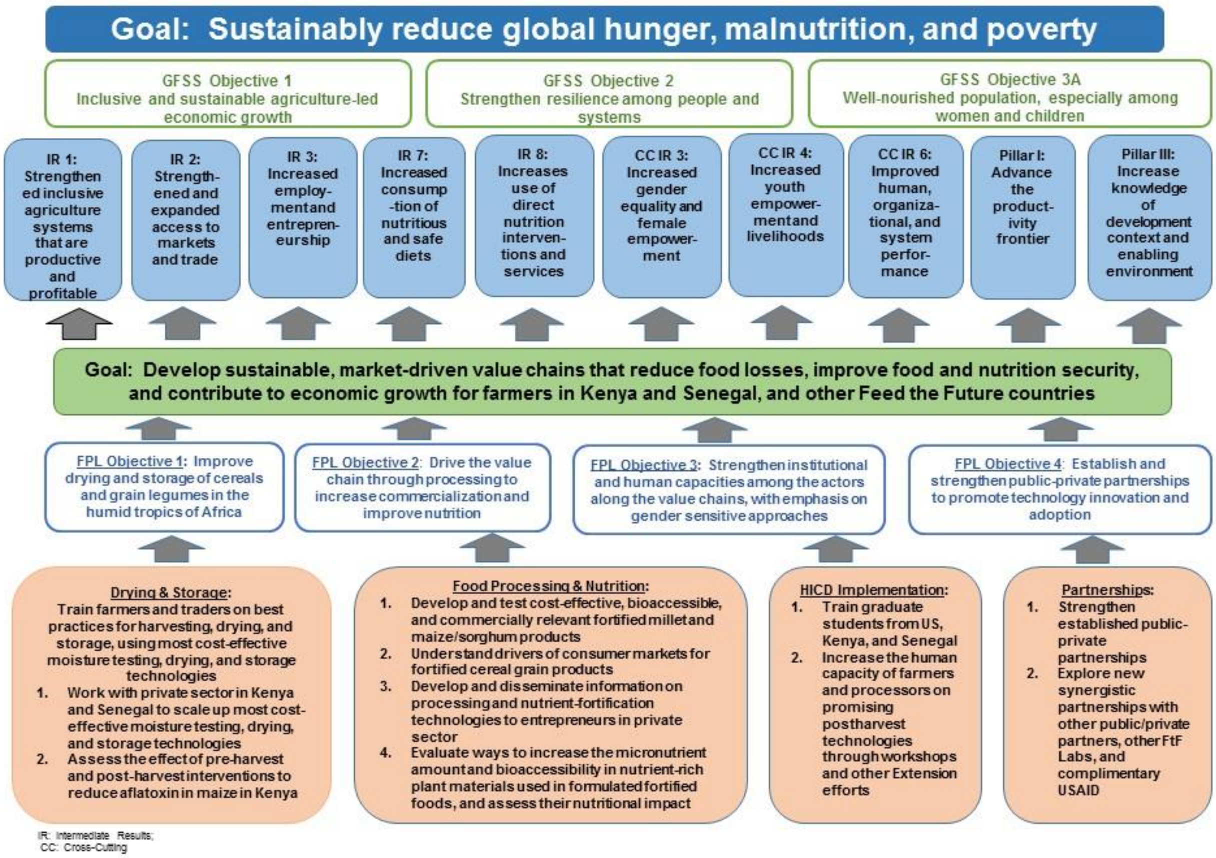
Over one third of the food produced is lost after harvest worldwide. In most developing countries (including Feed the Future countries), the losses are mostly associated with post-harvest challenges, including toxin-producing molds that proliferate under insufficiently dry storage conditions and limited value addition opportunities. These losses can be mitigated through proper post-harvest handling (drying, moisture measurement, and storage) and through a strong food-processing sector that serves as a market-pull for farmers and contributes to improved nutrition leading to enhanced resilience. The Food Processing and Post-Harvest Handling Innovation Lab addressed these issues through the development of cost-effective on-farm drying and storage technologies, food-processing innovations, including nutritionally-enhanced product development, and mechanisms of dissemination that link farmers to markets.

**Impact Pathway**: (original document developed)

| OUTPUTS | OUTCOMES | IMPACTS |
|---|---|---|
| • Technologies and innovations to improve quality and safety of grains and legumes after harvest<br>• Diversify high quality and nutritious food products that drive markets<br>• Evidence of strong public/private partnerships in reducing losses<br>• Capacity for post-harvest research and development strengthened | • Improved grain handling and storage capacity<br>• Improved quality and safer grains and legumes that meet local and international standards<br>• Increased access to safe, high quality and nutritious food products<br>• Improved market opportunities and access for farmers<br>• Improved quality of life for women and children | • Reduced post-harvest losses in FTF countries<br>• Improved food and nutrition security in FTF countries<br>• Increased family incomes |

**Theory of Change for FPL:**

Attachment 4: Illustrative Theory of Change for FtF Food Processing Innovation Lab, Phase II



# ADMINISTRATION

***Management Entity:***

- Director: Dr. Betty Bugusu (2014-18); Dr. Suzanne Nielsen (2019)
- Deputy Director: Dr. Suzanne Nielsen (2014-18)
- Project Manager: Heather Fabries (2014-17); Julie Hancock (2017-19)
- Project Assistant: Lonni Kucik
- Business Office Assistant: Laura Bergdoll (2014-2017); Tasmia Kashem (2017-19)
- Business Office Manager: Beth Siple

***Technical Committee:***

- Project Director: Betty Bugusu
- Project Deputy Director: Suzanne Nielsen
- Project Manager: Heather Fabries (2014-17); Julie Hancock (2017-19)
- Team Leader, Drying and Storage: Jess Lowenberg-DeBoer (2014-17); Jacob Ricker-Gilbert (2017-19)
- Team Leader, Processing and Nutrition: Bruce R. Hamaker

***External Advisory Committee:***

- Tahirou Abdoulaye, Ph.D., Outcome/Impact Economist, International Institute of Tropical Agriculture (IITA), Headquarters & West Africa Hub, PMB 5320, Oyo Road, Ibadan 200001, Oyo State, Nigeria
- John Bustle, Ph.D., Retired Head, John Deere Foundation, Geneseo, IL
- Bruce Maunder, Ph.D., Retired, DEKALB Genetics Corp, Lubbock, TX
- Joseph Mpagalile, Ph.D., Agro-Industries Officer, Food Processing and Nutrition, Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00153 Rome, Italy
- Dirk Maier, Ph.D., P.E., Professor of Grain & Feed Operations & Processing, Dept. of Agricultural & Biosystems Engineering and Associate Director, Global Food Security Consortium, Iowa State University, Ames, IA
- Angela Records, Ph.D., Agreement Officer Representative, International Agricultural Research Advisor, Research Division, Office of Agriculture, Research and Policy, Bureau for Food Security, USAID, Washington, DC.

***USAID Agreement Officer Representative:***

- Dr. Angela Records

***Project Launch:***

The FPL project was launched in August 2014 in Dakar, Senegal, in a meeting involving project investigators and partners. The meeting included gender training for all project participants. Discussions took place to develop work plans, a performance management plan, and statements of work for collaborators.

# OVERVIEW OF ACTIVITIES, ACCOMPLISHMENTS, AND UTILIZATION OF OUTPUTS

## Objective 1 - Drying & Storage:

### Investigators & Research Team Members:

***U.S.A.:***

Dr. Jacob Ricker-Gilbert, Asst. Prof., Dept. Agricultural Economics, Purdue Univ. (Team Leader for Drying & Storage, 2017-19)
Dr. Corinne Alexander, Assoc. Prof., Dept. Agricultural Economics, Purdue Univ. (Died in Jan. 2016)
Dr. Jonathan Bauchet, Asst. Prof., Dept. Consumer & Family Studies (Became involved in project after Corinne Alexander passed away)
Dr. Guibing Chen, Asst. Prof., North Carolina Agriculture & Technology State Univ. (Involved in project 2014-17)
Dr. Klein Ileleji, Assoc. Prof., Dept. Agricultural & Biological Engineering, Purdue Univ.
Dr. Cheryl O'Brien, Asst. Prof., San Diego State Univ.
Dr. Arvind Raman, Asst. Dean, College of Engineering, Purdue Univ. (involved in project 2016-2019)
Dr. Richard Stroshine, Prof., Dept. Agricultural & Biological Engineering, Purdue Univ. (involved in project 2016-2019)
Dr. Charles Woloshuk, Prof., Dept. Botany & Plant Pathology, Purdue Univ.

***Kenya:***

Dr. Hugo De Groote, Principal Scientist, Agricultural Economics, CIMMYT, Nairobi, Kenya
Dr. Patrick Ketiem, Senior Research Officer, Climate change/Agro-Processing, KALRO, Kakemega, Kenya (involved in project 2016-2019)
Bernard Munyua, Research Associate, Agricultural Economics, CIMMYT, Nairobi, Kenya
Dr. Charles Bett, Agricultural Economist, KALRO, Machakos, Kenya

***Senegal:***

Dr. Ibrahim Sarr, Head of Entomology Lab/Coordinator of Natural Resources Management Prog., ISRA, Dakar, Senegal
Dr. Moussa Sall, ISRA, Dakar, Senegal

### Overall and Specific Objectives

**Overall Objective 1: Improve drying and storage of cereals and grain legumes in the humid tropics of Africa (focus on Kenya and Senegal)**

**Specific Objectives:**

Activity 1.1: Identify drying and storage methods used by farmers and determine moisture content of grain stored by farmers
Activity 1.2: Develop a low-cost moisture determination method
Activity 1.3: Develop low-cost grain drying technologies for smallholders
Activity 1.4: Determine the optimum moisture for safe storage of grains and oilseeds in hermetic storage systems, and the potential for aflatoxin development in hermetic bags
Activity 1.5: Conduct socio-economic assessment of grain drying and storage alternatives for smallholder farmers, farmer associations, small-scale grain traders and food processors

## Activity 1.1: Identify drying and storage methods used by farmers and determine moisture content of grain stored by farmers

***Overview of Specific Activities:*** (done over first two years of project)

- Installed a weather station at sites for focus in Kenya and Senegal
- Gathered baseline data on local post-harvest practices and issues in Kenya and Senegal
- Conducted an economic baseline study of the value of improved grain drying in Kenya and Senegal comparing current practices with alternative technologies
- Compared how men vs. women access grain drying, grain moisture determination and storage information to inform gender sensitive extension efforts

***Accomplishments and Utilization of Outputs/Outcomes:***

- HOBO weather stations (manufactured by Onset Computer Corporation, Bourne, MA, USA) were installed in: 1) Kakamega, Kenya at the KALRO field station, and 2) Velingara, Senegal at the ISRA field station. The weather stations consisted of the following: HOBO u30 NRC data logger, temperature/relative humidity (RH) sensors, rain gauge, wind speed and direction sensor, solar shield for temperature/RH sensors, solar radiation (pyranometer) sensor, small solar panel kit, data logging software/cable, and a 2-meter tripod stand/cross arm with accompanying mounting accessories.
  - Utilization of Outputs: Data collected from installed weather stations were used to evaluate the impact of weather on both drying and storage in the regions, and to help design best management practices for smallholder maize cropping systems.
- A baseline study of smallholder farmer grain post-harvest handling practices for maize in Kakamega, Kenya and Velingara, Senegal was done using visits and household surveys (engineering and socio-economic) to gather data on local post-harvest practices and issues in Kenya and Senegal (grain drying, storage, and moisture measurement). The study included determining the moisture content and quality (kernel disease, insect count and aflatoxin contamination) as maize moves from the field at harvest to the barn or home for storage.
  - Results in Kenya showed the following: 1) There is need for training on best practices on maize post-harvest handling, 2) Simple low-cost drying and moisture measurement technologies will help farmers attain good quality maize, and 3) Over 70% of the maize grown in Kenya is used for household consumption, which indicates that increasing on-farm grain storage evens consumption patterns and helps to reduce food insecurity.
  - Results in Senegal showed that farmers often did not use appropriate post-harvest equipment. For example, laying crops on the bare ground in the open air was the primary method used of drying, resulting in soil contamination. Drying on bare ground seems to be the major source of the Aspergillus fungus and subsequent aflatoxin accumulation during drying and storage, and farmers need training on sanitary drying method such as use of plastic sheets to prevent grain contamination.
    - Utilization of Outputs: Results from surveys and the baseline studies were incorporated in designing various interventions.
- An economic baseline survey was done to determine willingness to pay (WTP) for post-harvest technologies. Results showed the following: 1) Drying on tarps to reduce grain contamination received positive feedback in the trainings in both Kenya and Senegal. 2) There was some willingness to pay for tarps and dryers with a capacity of 100 kg and costing less than United States dollar (USD) 100, and 3) Auction results indicated that consumers and traders preferred dried maize when they knew the moisture content. However, they could not distinguish between unlabeled maize dried to ≤13.0% and 14-15.0% moisture content.

  - Utilization of Outputs: Results of this research were used to design extension and training material that were used in subsequent years of the project.
- Gender-focused studies (16 focus group discussions with men and women farmers in 8 villages) were done in farming communities and households in Kenya and Senegal to better understand post-harvest losses, specifically issues related to post-harvest losses and the perception of women's and men's roles in farming and household practices. The intent of the survey was to provide insight into farmers' perspectives of roles, rights, responsibilities, entitlements, and obligations for females and males. Results showed diverse and often conflicting perspectives among men and women in both countries.
  - Utilization of Outputs: Results were used throughout the remainder of the project to help design interventions, including training programs. Specifically we want to understand how women engage in post-harvest activities and if any of the technologies we have introduced impact women's burden, either positively or negatively. In addition as we will discuss later in the report, we are starting to engage with youth groups to sell post-harvest inputs such as tarps, hygrometers, and Purdue Improved Crop Storage (PICS) bags in Kenya and Senegal.

## Activity 1.2: Develop a low-cost moisture determination method

***Overview of Specific Activities:***

- Reviewed literature/local capacity on the four moisture determination methods outlined in the proposal
- Calibrated moisture determination methods developed by FPL partners
- Developed a moisture determination protocol for the relation between moisture content and volume of kernels
- Developed moisture measurement protocol and calibration for determining moisture content of corn using the salt-in-jar method
- Developed and evaluated moisture content testing protocols that use inexpensive humidity/temperature devices, including the use of a hygrometer
- Determined the effect of wetting and drying cycles on error in moisture determination of maize using the hygrometer method
- Compared the measurement of maize moisture using the hygrometer, the USDA-ARS (United States Department of Agriculture – Agriculture Research Service) probe, and the commercial John Deere Model SW5300
- Tested a low cost dry strip color changing option for measuring moisture content in maize

***Accomplishments and Utilization of Outputs/Outcomes:***

- Work on development and calibration of moisture determination methods was done for background knowledge to develop a relatively accurate method to rapidly test the moisture content of a small volume of maize prior to hermetic storage. A method was developed for quickly and accurately counting the maize kernels from a bulk sample for moisture determination, based on kernel dimensions. (Moisture measurement of the grain is based on the pre-determined dry weight of 1000 kernels.)
  - Outcome: This counting plate became the standard system used to compare moisture determination methods. Details from the testing were used to develop the information for the 'rack card' on instruction for testing moisture content of grain.
- A Xikar thermo-hygrometer (USD 30, on-line retail) with a calibration feature was tested against a much more expensive commercial grain moisture meter (USD 95) (Dickey-John) for accuracy in measuring moisture content on grain. Results showed that the hygrometer consistently gave accurate moisture measurements comparable to that of the grain moisture meter.

  - Utilization of Outputs: Results led to the testing of a much less expensive hygrometer to assess moisture content of grain prior to storage.
- A simple, low-cost method was developed (using a low-cost hygrometer) to determine moisture content of maize before storage. The method is based on the equilibrium moisture content /equilibrium relative humidity (EMC/ERH) relationship for maize. Five types of inexpensive hygrometers were tested for their ability to measure equilibrium relative humidity (RH) of maize to then calculate maize moisture content. For the hygrometer that proved to be most promising, a protocol was developed for using the hygrometer as a tool to help farmers determine when grain is dry enough for safe storage. This Mini Digital Hygrometer is mass manufactured and available at the wholesale level for about USD 1.00 and it retails for <USD 2.00 in the USA. It gives temperature and relative humidity readings. Equilibrium relative humidity (RH) of 65% at temperature of 20-30$^{o}$C indicates a moisture content of 12.5 to 13.5% (moisture equilibrium is established in 15-20 min). In the final protocol developed, a handfull of maize is placed in a small, sealable plastic bag along with the hygrometer. If the relative humidity reading is above 65%, the grain is too wet for safe storage. Below 65% RH, the grain is ready for storage.
  - Utilization of Outputs:
    - Results from using the hygrometer to test effect of wetting and drying cycles of maize, and from comparing hygrometer to other commercial instruments, were used to determine error sources and correction factors when using a hygrometer for grain moisture determination. This information was essential to develop the final protocol for use of the hygrometer.
    - Results from calibrating and testing the hygrometer in the US for grain moisture measurement led to deployment to Senegal and Kenya for field testing.
    - Overall, results led to introduction of the hygrometer for testing grain moisture content to farmers, extension agents, grain traders, and others involved in FPL training and research trials in Senegal and Kenya.
- Cobalt chloride humidity sensor strips (a paper moisture test strip; "Dry Card") being used by the Horticulture IL for moisture determination were tested at 65% relative humidity, as a possible cheap and effective method to estimate moisture content of grain prior to hermetic storage. Results showed that this method was not sensitive and reliable enough (i.e., could not obtain a sharp color break, from blue to pink, on test strip) for farmers to make an accurate enough decision about moisture content of grain prior to hermetic storage.
  - Utilization of Outputs: Findings led to discontinuing the efforts to apply the Dry Card to testing of grain moisture prior to hermetic storage, because of concerns that the device provides inaccurate readings and does not reach an equilibrium moisture level.
- A willingness-to-pay (WTP) study was done regarding hygrometer usage by farmers and traders in Kenya. The Purdue team interviewed 580 people, including 305 farmers and 284 traders, from the Kakamega district in Kenya. Feedback on the hygrometer was positive, with its use most appreciated when the grain moisture was at the borderline for safe storage (14%). Results showed that people consistently think the grain is dry, but when shown the hygrometer reading indicating it is not low enough in moisture content to be safe, they express interest in buying a hygrometer. The mean willingness to pay for the hygrometer was USD 1.21 for farmers and USD 1.15 for traders. The median willingness to pay for the hygrometer was USD 1.00 for both farmers and traders. In an analysis of the supply side of the market, the optimal retail price of the hygrometer was estimated to be about USD 1.90.
  - Utilization of Outputs: Results led to continued effort toward commercialization of the hygrometer for grain moisture determination prior to hermetic storage.
- A marketing test was done comparing the hygrometer and the Horticulture IL "Dry Card". When both the hygrometer and paper moisture test strips were available, 74% said they would prefer the hygrometer, saying that they thought the hygrometer to be more accurate than the card. However, due to lower cost of

producing DryCard locally in Africa, it would be more profitable for a manufacturer/distributor to sell the DryCard than the hygrometer.

- Utilization of Outputs: Efforts were initiated toward commercialization of the hygrometer method for measuring moisture alongside PICS bags, in collaboration with the local private sector in Kenya and Senegal. The hygrometer has been test marketed in Kenya through Bell Industries, a local company that manufactures and markets PICS bags in Kenya. Bell Industries participated in the FPL-sponsored training workshops conducted. In Senegal COFISAC is working to obtain a license to manufacture and distribute PICS bags. SEDAB is the input supply company that sell PICS bags in their retail shops in Kenya. In phase II of FPL we plan to work with rural youth to become venders of hygrometers along with PICS bags, tarps and potentially other inputs. These relationships are already being built in Kenya and Senegal during Year 5 of the project.

- FPL and PICS project groups work together to add a plastic jar to the hygrometer (***Figure 1***) to make it a more standardized product compared to placing the device in a plastic bag containing grain (50g) for testing. We are working to commercialize the hygrometer in Kenya and Senegal and have improved the design of the hygrometer by adding a simple plastic jar for it (***Figure 1***). We are branding the device as the Purdue Improved Moisture Assessment (PIMA). Dieudonne Baributsa (Director, PICS Program at Purdue) has engaged PICS bags manufacturers on the possibility of producing a hygrometer product to be sold through the PICS supply chain. Additionally, Global Good continues to work on refining and improving the hygrometer, hoping to have a new prototype of the device ready for market testing by the end of 2019.
  - Outcomes: The PIMA system has been developed and is being tested for accuracy. We are working with the PICS manufacturer in Tanzania, Mr. Suraj Devani, Managing Director of PPTL Plastics, in Tonga to mass-produce the PIMA and sell it through the PICS distribution network. As mentioned we will work with local youth to bridge the last mile of the supply-chain.


***Figure 1***. Standardized product of hygrometer embedded in a plastic jar.

- The FPL hygrometer was assessed for scalability by a team of scaling experts during the Scale-Up Conference held at Purdue on September 25-27, 2018.
  - Utilization of Outputs: The team received useful feedback that is being incorporated in the commercialization efforts. Team members Jacob Ricker-Gilbert, Hira Channa, and Charles Woloshuk presented the scaling plan for the hygrometer to a panel of experts at the conference. The team received constructive feedback and the experts were generally positive about the potential of the device. ***Figure 2*** below shows how the hygrometer fills an important niche in the market for

moisture detection. It provides the best combination of accuracy and low cost of moisture detection devices on the market, in our opinion.

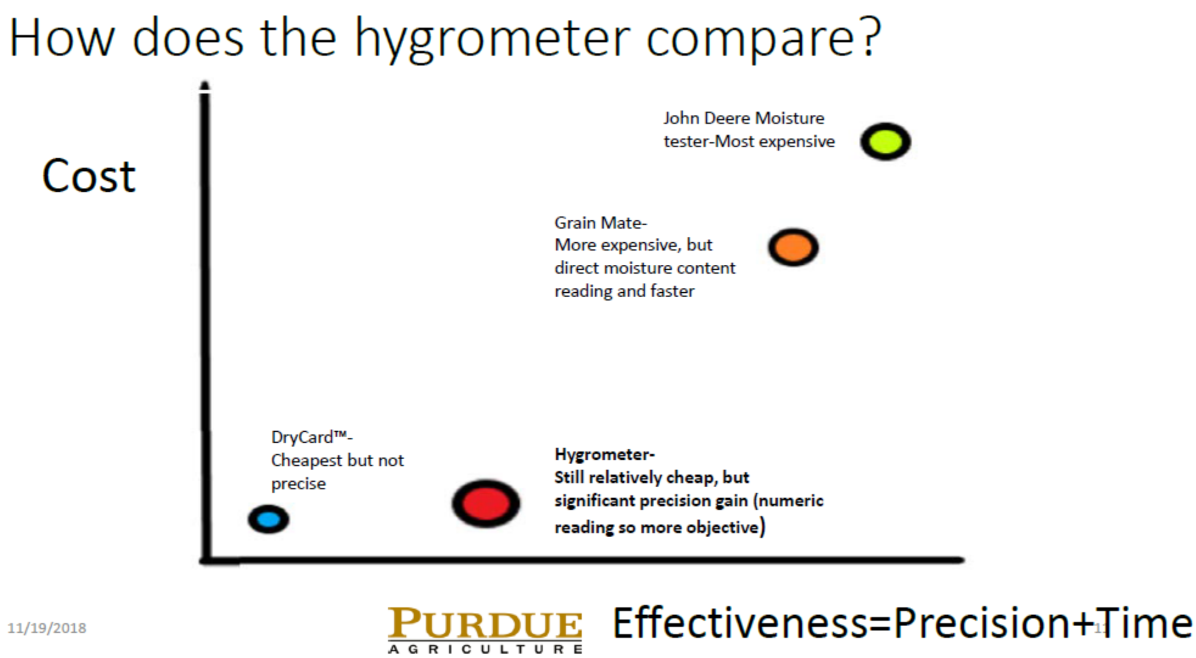



***Figure 2***: Comparison of hygrometer to other moisture detection devices

## Activity 1.3: Develop low-cost grain drying technologies for smallholders

***Overview of Specific Activities:***

- Determined the critical criteria for grain drying by smallholders in Kenya/Senegal, then applied those critical criteria and local conditions (based on data from weather stations) to drying systems design
- Finalized engineering drawings and fabrication protocols for the multipurpose solar cabinet dryer (version 2); Conducted field test at Purdue Agronomy Center for Research and Extension (ACRE) farm
- Manufactured test multipurpose solar cabinet dryer units for Kenya & Senegal
- Worked with the Post-Harvest Innovation Laboratory at Kansas State University (PHL) and other partners to test the FPL solar dryer, and other technologies in Kenya and Senegal
- Developed standard efficiency test protocols for grain dryers including drying time, labor requirement, and cost of equipment
- Implemented field testing of drying options on farms and on research stations and with partner organizations including farmer associations and food processors in Kenya and Senegal
- Completed modeling effort for multipurpose solar cabinet dryer (version 2) and validated with field data
- Purdue Office of Technology and Commercialization filed IP for the multipurpose solar cabinet dryer and the solar drying tray, and issued commercialization license to JUA Technologies International, which did the following:
    - Filed for trademarks with the USPTO, Dehymeleon™ and Dehytray™ for the multipurpose solar cabinet dryer and solar drying tray, respectively.
    - Launched the multi-purpose solar drying tray (DEHYTRAY™) to market in December 2018

- Pursued R&D to develop version 3 of multi-purpose solar dryer (the larger unit trademarked Dehymeleon™) toward commercial manufacturing and pilot test for commercialization

***Accomplishments and Utilization of Outputs/Outcomes:***

- Two multipurpose solar dryers and a solar grain dryer were designed at Purdue, then fabricated and tested at Purdue and on the field in Senegal and Kenya. These solar dryers were tested and refined at Purdue, then in Kenya and Senegal, to compare their economic performance against that of roadside drying:
  - The project initially intended to develop a biomass-fired drying stove, but the investigator involved was unable to overcome the engineering challenges associated with the prototype, including excessive smoke coming from the stove. After about two years of development, the focus was shifted to developing only solar-powered dryers.
  - The scalable cabinet solar dryer system developed (multi-purpose, Dehymeleon™) consists of a cabinet that has the capacity volume to hold 10 stackable solar drying trays (Dehytray™); trays are stacked 5 trays high side by side. The drying trays can be used as a stand-alone solar dryer, which is covered with acrylic windows (allows 92% sun-light through) that prevent contamination from the elements and pilferage by livestock or rodents, thus providing a hygienic drying environment. Because it is quite portable, it can be easily transported to the field, and moved to the most convenient location over the course of the day having best solar irradiation. It is best placed elevated on racks, which can be easily built locally, but can also be placed by laying on pebble rock bed, concrete floor, or on the ground for open-air drying applications. The solar drying trays can hold different types of crops like grain (corn, beans), processed cereals in granular or extruded form, or sliced and cut fruits and vegetables. A capacity table has been developed for the solar drying tray and is being updated as several crops become tested. For shelled corn, a tray can hold a capacity of up to 7.5 kg (about half full). Tests are being conducted on the effects of holding capacity on drying rates for shelled corn. Other accessories of the multipurpose solar dryer include cell phone charging ports on the electronics control and the possibility of using it as a solar-powered device by converting DC to AC power using an inverter (optional). The system was tested on various crops including maize, fruits, and vegetables. The multi-purpose solar dryer with trays half-filled and all fans working was faster (1.4 times) for drying maize grains than drying in the open air or on a tarp (version 2). This dryer is being commercialized through JUA Technologies International LLC (JTI), and has two multi-purpose solar dehydration devices: a) DEHYMELEON™ (multipurpose solar dryer and power generator), and b) DEHYTRAY™ (multipurpose solar drying tray; removable plastic trays) (***Figure 3***). JUA Technologies strategy is to deliver a multipurpose drying system to smallholder farmers who mostly grow more than one crop. Based on the drying team) interactions with farmers and extension workers during training in Senegal and Kenya (2015 and 2018), farmers were interested in a dryer that was able to dry multiple crops rather than just grain. Therefore, it would appear that a good strategy would be to market the dryer for high-value foods rather than for commodity crops, which once acquired, can also be used for commodity crops. The capacity of the trays is a limitation for large aggregators of grain, but not for smallholders surveyed in Kakamega, Senegal or Velingara, Kenya. In an effort to develop the multipurpose dryer (the large unit) toward commercial manufacturing and pilot test for commercialization, JUA Technologies is pursuing R&D though support of USDA-SBIR Phase I funding. In Senegal, youth and women groups are being training and supported for drying and storage technology distribution and service providing, in cooperation with the ANCAR extension agents. The DEHYTRAY™ trays can be used as a stand-alone solar dryer. Under some weather conditions, the drying rate with these trays exceed ambient open sun-drying, especially in poor weather conditions, and provides a better phytosanitary drying environment than typical open-air drying.

***Figure 3.*** Multipurpose cabinet solar dryer and drying trays

- Solar wrap dryer (Picosolar crOp Dryer, POD) (***Figure 4***) designed for on-farm use by smallholder farmers (criteria of 90 kg/day capacity, one hour or less of manual labor, cost of less than $100, and can be disassembled and transported by motorcycle). This dryer has been redesigned multiple time to increase thermal efficiency and reduce costs. KALRO tested the redesigned POD in five sites in Kenya: Nakuru, Uasin Gishu, Trans Nzoia, Nandi, and Bungoma. Results in Trans Nzia suggest that up to 12% moisture content was removed in 10 hours using the POD. In Uasin Gishu up to 10% moisture content was removed in 2 hours under favorable conditions.
    - Outcomes: The solar wrap dryer is being field tested in Kenya. The DEHYTRAYs are being sold and marketed globally by JUA technologies, founded by Klein Ileleji. We will work with Ileleji to track sales of the DEHYTRAY moving forward but will not spend more FPL funds to develop new dryers.

***Figure 4*****.** Picosolar crOp Dryer (POD) with aluminum fan frame tested during the summer of 2018. Left picture shows the maize in the trays with the fan frame positioned along the side of the trays. The right picture shows the POD trays with the plastic sheet in place, fans running, and a 30 Watt solar panel.

## Activity 1.4: Determine the optimum moisture for safe storage of grains in hermetic storage systems, and the potential for aflatoxin development in hermetic bags

***Overview of Specific Activities:***

- Conducted trials to determine safe storage moisture for grains and oilseeds in hermetic storage
- Determined impact of grain moisture on mold growth and aflatoxin accumulation during hermetic storage in Senegal and Kenya

- Examined the impacts on maize storage in PICS and woven bags on its quality and fungal populations
- Determined effect of Aflasafe® treatment of maize on fungal populations and aflatoxin accumulation in hermetic storage

***Accomplishments and Utilization of Outputs/Outcomes:***

- An experimental auction was conducted in Senegal to test differences in trader and consumer willingness to pay for wet and dry maize. Results showed a preference for dry maize when traders and consumers knew the moisture content. However, they could not distinguish between unlabeled maize dried to ≤ 13.0 % and 14-15.9% moisture content, hence the need for moisture measuring technologies.
    - Utilization of Outputs: Results confirmed the need for low-cost moisture measuring technologies, justifying the efforts that followed.
- Work was done to determine the most cost-effective way in Senegal to prevent aflatoxin contamination and spread of aflatoxin in the maize supply of rural subsistence households.
- Studies were done to determine the efficacy of PICS hermetic bags (***Figure 5***) (vs. mesh bags) to provide a moisture barrier under hot and humid conditions, the moisture content that allows for aflatoxin production during storage, and the effects of routine opening of PICS bags. Results showed the following: 1) PICS bags (vs. mesh bags) protected dried maize from insect growth and moisture from the environment, 2) PICS bags serve as a barrier to moisture exchange, thus significantly reducing environmental effects on stored maize, and 3) Maize should be properly dried prior to storage in PICS bags, 4) Fungal growth increased dramatically when grain moisture was 16% or higher, and 5) Repeatedly breaking the hermetic seal of the bags increases fungal growth and the risk of aflatoxin contamination, especially in maize stored at high moisture content (15%, 16%, 18%, and 20%) under warm tropical conditions.
    - Utilization of Outputs: Results of this study, along with previous literature, led to the criteria and recommendations used in the project: To assure no fungal growth occurs in stored maize, it should be dried within 3 days of harvest to ≤ 13% moisture content.


***Figure 5***. Purdue Improved Crop Storage (PICS) bags

- A study was done to test the efficacy of hermetic bags (PICS and A to Z Textile) with regard to moisture, aflatoxin accumulation, and pest control for maize storage in Kenya and Senegal. Fungal microbiome of grain stored in the U.S. changed very little during storage, whereas the fungal microbiome of the Kenya grain changed significantly. Bag type was the most important factor influencing changes in fungal microbiome during storage.
    - Utilization of Outputs: Results of the research were presented at a stakeholders meeting in Nairobi in October. Private-sector hermetic bag manufacturers, NGO and government officials attend. The presentation title was "Evaluation of hermetic storage and its effect on insect growth, fungal growth,

mycotoxins, food quality, and seed germination in maize". How they used that information is not known for now.

- Experimental protocols were developed to determine the fungal species community associated with stored maize. The protocols rely on "next generation sequencing" method and informatics to identify and quantify fungal species.
- The impact of pre-harvest biocontrol treatment to reduce post-harvest aflatoxin accumulation during the drying period was tested. Higher moisture content resulted in more rapid growth of fungi, an increase in maize kernel infection, and increased populations of *A. flavus* strains.
  - Outcomes: Results pointed to the critical need to measure and control moisture content of maize to prevent aflatoxin development.
- Researchers are assessing effects of pre-harvest biocontrol-treatment of maize on postharvest risk of aflatoxin accumulation (i.e., maize with and without Aflaguard biocontrol treatment). Results showed that for maize at 20% moisture content, fungi, including *A. flavus*, grew and spread rapidly. Both aflatoxigenic and non-aflatoxigenic strains of *A. flavus* increased during the incubation period. The presence of biocontrol strains did not appear to influence the growth or aflatoxin production by wild-type strains.
  - Utilization of Outputs: Based on these results, in the next phase of FPL we will conduct an intervention with farmers to identify pre-harvest treatments that can be combined with post-harvest training to reduce aflatoxins. The component will focus in Western Kenya, where we will see if bio-control agents such as Aflasafe can be incorporated into post-harvest training to reduce aflatoxin in stored maize.

## Activity 1.5: Conduct socio-economic assessment of grain drying and storage alternatives for smallholder farmers, farmer associations, small-scale grain traders and food processors

***Overview of Specific Activities:***

- Determined the critical criteria for grain drying by small holders in Kenya/Senegal
- Identified the most promising grain drying alternatives for various users in Senegal and Kenya, including on-farm drying on smallholder farms, farmer associations, grain traders of various sales, and food processors
- Implemented on-farm grain drying experiment, comparing 1) training only, 2) training + hygrometer, 3) training + hygrometer + tarp, and 4) training + hygrometer + tarp + 1 PICS bag
- Inventoried grain dryers currently on the market or being tested in Kenya, and estimated cost of drying with each, for comparison with cost of roadside drying
- Conduct endline surveys on drying moisture determination and storage practices in Kolda and Velingara, Senegal, and in Kakamega, Kenya
- Work with existing and newly collected data to understand gender impacts of drying and storage in Kenya and Senegal

***Accomplishments and Utilization of Output/Outcomes:***

- A study was done to determine the economics of roadside drying, for comparison to economic performance of solar and other dryers. Results showed that open-air maize drying is a very low- margin business in Kenya. Operators make more money from transporting maize than from drying maize. Although drying is a necessary step in the supply chain, it is not a very profitable business in and of itself.

  - Utilization of Outcomes: This finding highlights an important point, that maize drying is not a profitable business by itself. Therefore, it will be difficult to bring a dryer to market for smallholders in SSA that is more cost-effective than the sun. The scale of production by smallholder farmers needs to increase before this becomes feasible. As a result of this study, we will not invest more FPL funds into developing maize dryers in phase II. Instead we will promote use of tarps and raised platforms for clean and sanitary solar drying, along with moisture testing using hygrometers and storage in PICS bags.
- In endline surveys on drying moisture determination and storage practices, 2,000 households in Velingara, Senegal who were trained and received post-harvest inputs in 2017 are currently being re-surveyed and aflatoxin samples are being taken. The goal is to see if benefits last longer and if there is spill-over information occurring to other households in these communities.
  - Utilization of Outcomes:
    Results suggest that there are some benefits from the technologies and training in the form of lower aflatoxin levels after two years. This suggests that these interventions can be cost-effective and should be promoted.
- In Kakamega, Kenya, the goal of the endline survey was to assess the willingness to pay and the level of adoption for the hygrometer from Purdue Univ. and the DryCard™ from the Univ. California, Davis, two years after an initial willingness-to-pay auction was conducted in 2017 with the same respondents. On average, respondents were willing to pay 120 KSH ($1.20) for the hygrometer and 90 KSH ($.90) for the DryCard™. When asked which device the respondent would prefer to purchase at their own value of both devices, 73% said they would prefer the hygrometer, even at a higher price. 66% of households who purchased a hygrometer in 2017 still use it while 62% of households who purchased a DryCard in 2017 still use it. There is also evidence that people share their devices with their neighbors, as 20% of people who purchased the hygrometer and 16% of people who purchased the DryCard in 2017 shared it with at least one other household during the 2018 long rainy season. We also conducted an auction in Eldoret, a surplus producing region of Kenya, to test if there was demand from small-scale traders for a moisture testing service provider model where a third party, like a youth group, could test peoples' moisture content in maize using a hygrometer or commercial meter for a fee. Results suggest that the profit maximizing price for a third party operator to charge a trader for a moisture test is $0.30 using a hygrometer and $0.50 using a commercial moisture meter. This suggest that a testing service using a hygrometer could be very profitable, given its market price of $2.50, an operator could recuperate the cost of the device quickly. It would take much longer to recuperate the investment in a commercial moisture meter that costs around $300.
  - Utilization of Outcomes:
    The results of this study lead us to believe that there is a market for hygrometers both as a testing service and as a third party verification tool that could be a business for someone, potentially rural youth. We are going to continue to promote these business models in Senegal and Kenya.
- The FPL Gender Specialist is working with the drying and storage team: 1) to combine data collected in Vélingara, Senegal, from the initial gender study with that collected in January 2019 for a gender-based analysis, toward a peer-reviewed publication, and 2) to publish drying and storage findings from focus group discussion data collected in Kenya and Senegal (manuscript being prepared for *World Development*).
  - Outcome:
    We will use the information on gender related outcomes to inform our work and ensure that we are promoting technologies and practices that empower women and youth.

# Objective 2 - Food Processing and Nutrition:

## Investigators & Research Team Members:

**U.S.A.:**

Dr. Bruce Hamaker, Prof., Dept. Food Science, Co-Director of IFTC, Purdue Univ. (Team Leader for Processing & Nutrition)

Dr. Mario Ferruzzi, Prof., Dept. Food Science and Dept. Nutrition Science, Purdue Univ. (Moved to North Carolina State University, but continued involvement)

Dr. Cheryl O'Brien, Asst. Prof., San Diego State Univ.

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Dr. Hugo De Groote, Principal Scientist, Agricultural Economics, CIMMYT, Nairobi, Kenya
Mr. Bernard Munyua, Research Associate, Agricultural Economics, CIMMYT, Nairobi, Kenya
Dr. Augostino Onkware, Prof., Univ. Eldoret, Eldoret, Kenya
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***Senegal:***

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Mr. Fallou Sarr, Director of External Relations, ITA, Dakar, Senegal

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## Overall and Specific Objectives

**Overall Objective 2: Drive the value chain through processing to increase commercialization and improve nutrition**

**Specific Objectives:**

Activity 2.1: Assess market demand and drivers for processed food products, comparing conventional and instant cereal-based products, with and without nutritional enhancement
Activity 2.2: Evaluate nutritional composition of plant materials and the micronutrient retention/bioaccessibility when in food products; Research and evaluate ways to increase micronutrient amount and bioaccessibility in nutrient-rich plant materials
Activity 2.3: Identify, develop, and refine food products and processes for cost effective, bioaccessible, and commercially relevant fortified millet and maize/sorghum products (for both rural and urban markets in Kenya and Senegal)
Activity 2.4: Begin to evaluate nutrition impact of program

## Activity 2.1: Assess market demand and drivers for processed food products, comparing conventional and instant cereal-based products, with and without nutritional enhancement

***Overview of Specific Activities:***

- Developed tools and approaches for assessment of market demand and drivers of nutritionally-enhanced products
- Conducted market assessment studies and evaluated outcomes to inform product development efforts
- Worked with processor partners in Touba, Senegal and Eldoret, Kenya to assess cost of production and transport to larger urban centers
- Conducted consumer willingness-to-pay (WTP) and preference studies to test urban mid-low and middle-economic consumer interest in fortified instant foods and instant foods alone
- Conducted home-use test to determine consumer potential of instant flours
- Conducted point-of-sale consumer acceptability and willingness-to-pay studies in Kenya to assess market potential, using refined fortified products
- Held stakeholders meeting in Eldoret, Kenya to determine entrepreneurs' desire to use extrusion technology, and met with government officials in Senegal to explore partnering to expand extrusion processing of instant fortified millet-based products

***Accomplishments and Utilization of Outputs/Outcomes:***

- Market assessment studies were done to identify potential drivers for processed and nutritionally-enhanced processed products among different socio-economic groups. Drivers identified included nutrition, cost, satiety value of products, convenience, and energy-saving potential.
  - Utilization of Outputs: Studies provided direction in focus of product development work on the project
- Sorghum varieties with different tannin levels were tested for taste acceptability in rural and urban settings in Kenya. While it was expected that low tannin or tannin-free sorghum types would be preferred in sorghum foods, some characteristics such as color of high tannin types were acceptable to consumers. Rural and urban consumers showed some differences in preferences, such as rural consumers preferred the smell of low or tannin-free types.
  - Utilization of Outputs: Information obtained was used in development of blended instant maize plus sorghum-based products.
- Consumer studies on acceptance and WTP were done with fortified products in Eldoret, Kenya, Touba, Senegal, and Dakar, Senegal (***Figure 6***) The studies showed high interest and WTP for instant (compared to traditional) and fortified food products (when information about fortification was provided). The studies with Kenyan consumers showed preference toward whole grain products (compared to decorticated grain).
  - Utilization of Outputs: Results confirmed reason to focus on instant, fortified, whole-grain food products in product development efforts.

***Figure 6***. Preparation of samples for a sensory study in Dakar, Senegal

- A market study was done on cereals and legume flours consumption in Kenya. The market study showed that consumers generally had some nutritional knowledge of local foods. Buyers preferred to include millet, sorghum, pumpkin seeds, and amaranth in their composite flours. Cowpea flour was mainly used as a fortificants to increase protein quantity.
    - Utilization of Outputs: Results helped further determine composition of developed instant food products that would be acceptable to consumers and successful in the marketplace
- Using products developed in the project, consumer acceptability tests and WTP studies were done in Senegal and Kenya to test the instant millet flour products that were fortified with natural fortificants. Results showed that products were acceptable to consumers, and the consumers were willing to pay more for instant flours compared to traditional products. In Kenya, the market for instant flours was better for thin rather than for thick porridge.
    - Outcomes: Positive results in the studies attracted donor and government interest to attend meetings that included government officials, scientists from Consortium of International Agricultural Research Centers (CGIARs), and others (as further described below).
- Consumer acceptability and market testing of fortified instant products was done in Kenya, and, in Senegal, a large sensory study (145 participants) was completed on the best four formulated nutrient-fortified extruded instant flours, and were tested as thin and thick porridges. Results are being analyzed. In Kenya, a point-of-sale acceptability and WTP study (~240 participants) was conducted on the final two best formulated fortified instant flours to understand consumer acceptability and interest.
    - Outcomes: These two studies were completed in March and April of 2019, and results are currently being analyzed.
- Stakeholder meetings were held with processors, policymakers, and grain growers in Nairobi.
    - Outcomes: In Kenya, interest in the Incubation Center proved to be high and growing.
- At the University of Eldoret, the FPL-supported Food Processing Training and Incubation Centre (FPTIC) became fully functional, serving the purpose of training prospective entrepreneurs as well as university students in small business development. CGIAR Nairobi offices of the International Potato Center (CIP) and International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) visited the Incubation Center.
    - Outcomes: Visit by CIP to the Eldoret FPTIC led to initiation of CIP-related activities, including a research and development (R&D) function on orange-fleshed sweet potato.
- Multiple meetings have been held in Senegal with government officials on a joint activity that will expand Mme. Mbacke's processing facility in Touba and initiate extrusion processing of fortified food products in two

other areas of the country.  A meeting at ITA was also held with the director of Cellule de Lutte Contre la Malnutrition (CLM), Mr. Abdoulaye Ka, regarding processing and increase of capacity for nutrient-fortified extruded instant flours.

  - Outcomes:  The office of Cellule de Lutte contre la Malnutrition (CLM), Programme de Renforcement de la Nutrition, which leads programs directed at decreasing malnutrition in Sénégal, placed orders for instant fortified millet flours.

- The Gender Specialist held focus group discussions on food processing in Senegal (Dakar and Touba) in January 2019.  These discussions focused on perception of the benefits, opportunities, barriers, and weaknesses of the food processing systems available through the FPL project.  The intent was: 1) to hear the processors' perspective of the relationship between processing innovation centers or other programs available to help processors in Senegal, and 2)to  better understand the local gender dynamics related to food processing.
  - Outcomes:  Results from the study are currently being analyzed, and will help inform the food processing work of the project in Phase II.

## Activity 2.2: Evaluate nutritional composition of plant materials and the micronutrient retention/bioaccessibility when in food products; Research and evaluate ways to increase micronutrient amount and bioaccessibility in nutrient-rich plant materials

(Intended Purpose:  Leverage local agriculture commodities to produce nutritionally-enhanced food products and to create a sustainable market-led fortified processed grain foods approach)

***Overview of Specific Activities:***

- Selected nutrient-dense plant materials from Senegal and Kenya and did screening of these for use at household level and in product development
- Established supply chain of high-priority plant materials
- Developed micronutrient stability testing in nutrient-dense ingredients and products
- Estimated bioaccessibility of critical nutrients and micronutrients in local plant food stuffs and prototype food products
- Tested the effect of locally-sourced plant materials on ability to increase in vitro bioaccessibility of iron, zinc, and provitamin A carotenoids
- Selected normal and biofortified millet varieties for use in product development
- Conducted *in vitro* mineral availability studies to determine if increased iron and zinc contents of biofortified millet outweighed negative effects of anti-nutrients

***Accomplishments and Utilization of Output/Outcomes:***

- Standard Operating Procedures (SOPs) were developed for material procurement and handling related to micronutrient screening and product development.
- An initial screening for provitamin A carotenoids and mineral contents was done with 30 distinct dried plant materials from Senegal and Kenya.  Select materials were prioritized for further product testing and incorporation into cereal-based products, specifically carrot, mango, and papaya for vitamin A, and baobab fruit, Lam (*Moringa sp*.), Oule, Nere, and Roselle (*Hibiscus sp.*) for iron and zinc contents.
  - Utilization of Outputs:  Results determined the initial target nutrient-dense plant materials for fortification of cereal-based food products.

- Drying methods were evaluated for production of nutrient-dense plant materials to be incorporated as fortificants in cereal-based products. Results showed that solar drying, using the multipurpose solar cabinet dryer (version 2), is a feasible method to generate carrot powders with high carotenoid retention to be used for vitamin A fortification.
- Further screening was done on nutrient-rich plant materials for use in consumer-based food products, with the following results: 1) Surprisingly high increases in *in vitro* bioaccessibility of iron and zinc were observed when baobab was added to whole grain instant millet porridges. 2) A sourdough-type fermentation approach, whether done in a traditional way or through addition of a culture or simply by adding lactic acid, reduced phytate and increased bioaccessible iron and zinc. 3) Formulation of millet instant products with baobab (bouy) and moringa seemed to stabilize carotenoids to extrusion processing. Results showed that co-extrusion of millet with the nutrient-rich plant materials is a good way to retain added carotenoid nutritional value.
    - Utilization of Outputs: Results further finalized which nutrient-dense plant materials would be used as fortificants.
- *In vitro* mineral availability studies showed that processed millet that was biofortified with iron and zinc contained higher levels of these micronutrients, with higher estimated bioaccessibility, than did processed normal millet varieties

## Activity 2.3: Identify, develop, and refine food products and processes for cost effective, bioaccessible, and commercially relevant fortified millet and maize/sorghum products (for both rural and urban markets in Kenya and Senegal)

***Overview of Specific Activities:***

Initial Work:
- Established contacts in Kenya and Senegal as primary processing locations and women's processor groups
- Developed prototypes for market assessment in Kenya and Senegal
- Developed and refined cereal processing methods to provide high-quality cereal products to local markets
- Developed the incubator (FPTIC) at Univ. Eldoret in Kenya
- Worked with established entrepreneur in Touba, Senegal, and helped enhance her processing facility to be used as an incubation center to train women processors
- At Incubation Centers, University of Pretoria, and Purdue University, developed and refined cereal processing methods to provide quality cereal products to local markets; worked toward instantized flour products with no cooking required

Product Development and Nutrient Fortification Work:
- Conducted extrusion study comparing decorticated and whole grain millet products (for purpose of using higher micronutrient whole grain products)
- Used decision tree approach to identify feasible fortification ingredients and blends and develop formulations for fortified products
- Optimized extrusion process and drying for lowest possible energy cost for instant flour production
- Completed cost analysis of extrusion process for instant flours in Kenya and Senegal
- Optimized the processing and sensory qualities of instant millet and maize/sorghum flours for consumer markets in Senegal and Kenya

- Conducted work on extruded whole grain products, their stability, and their potential in the Senegal and Kenya markets
- Developed a range of commercially viable ingredients and formulations for instant cereal products blended with micronutrient-rich native fruits and vegetables
- Assessed and optimized formulation and processing parameters that provide highest level of nutrient recovery and bioaccessibility
- Experimented with cost-effective drying systems to locally produce nutrient-rich dried ingredients from available fruits and vegetable
- Worked with processor partners to assess product, manufacturing, and transportation costs of products for entrepreneurs
- Conducted shelf-life studies of extruded millet-based ready-to-eat products through descriptive sensory evaluation and identification of factors responsible for limiting product shelf-life
- Underwent inspection of the Eldoret FPTIC incubator for approval for use in cereal processing; Standardized and certified formulations for test marketing among consumers
- Created specification sheets and manufacturing dossiers for each formulated product

***Accomplishments and Utilization of Output/Outcomes:***

Initial Work:

- In initial product development efforts, food products were developed in:
  1) Senegal: Instant extruded weaning foods were enriched with mixed fruits. Sensorial analyses showed preference for formulas enriched with papaya, followed by mango, then carrots. Analyses of beta-carotene content showed that the formula with carrots were significantly higher in amount of beta-carotene than with papaya or mango (***Figure 7***).
  2) Pretoria, South Africa: A ready-to-eat instant extrusion cooked sorghum-based porridge was enhanced in protein quality and mineral micronutrients through compositing with micronized (infrared cooked) cowpeas and a cowpea leaf relish. The product's contribution to protein and lysine recommended daily allowance was similar to that of commercial fortified corn-soy blend products, and the bioaccessibilty of its iron and zinc was much higher.
     - Utilization of Outputs: Studies helped determine which food products will be adopted by and refined in Kenya and Senegal.


***Figure 7.*** Single-screw extruder being used to produce instant extruded weaning foods enriched with select fruits and or vegetables, or with commercial micronutrients.

- A building provided by the University of Eldoret in Kenya was renovated by FPL to house the Food Processing Training and Incubation Center (FPTIC) (***Figure 8***). The building was fitted with basic food processing equipment and a lab for basic tests on grain for processing. The FPTIC of Eldoret was officially opened in July 2016. The Center is equipped with processing equipment for making high quality food products.
    - <u>Outcomes</u>: The Center was used throughout the rest of the project for product development and assessment studies, and for training women, men, youth processors, and university students.


***Figure 8***. Food Processing Training and Incubation Center (FPTIC) at Univ. of Eldoret in Eldoret, Kenya. Facility equipped with destoner, dehuller, milling machine, decorticator, extruder, dryers, baking ovens, refrigerator, and electric cooker.

- Extruder technology for processing instant flour was introduced in Kenya (***Figure 9***) at the FPTIC and also transferred in Senegal to Touba Darou Salam Processing Unit belonging Madame Mbacke, a long-time, private partner with ITA involved in technology dissemination.

***Figure 9***. Extruder being using in Food Processing Training and Incubation Center (FPTIC) during visit by Angela Records, USAID AOR.

<u>Product Development and Nutrient Fortification Work</u>:

- Studies were done to test the effect of processing technologies (decortication and extrusion) on flavor profiles and stability during storage. Extrusion decreased the lipolysis (fat breakdown) in whole grain millet flour, resulting in longer shelf-life.
    - <u>Utilization of Outputs</u>: Results supported the focus on extruded products in this project.
- Cereal-based high-quality processed products (traditionally milled or instant) and nutritionally-enhanced (with added synthetic vitamin-mineral premix or natural fortificants such as baobab and hibiscus) were

developed and tested for acceptability as thick and thin porridges. Instant flours were judged by the participants to be equal to or better in quality than the traditionally prepared porridge.

- <u>Utilization of Outputs</u>: Consumer test results supported the continued focus on instant extruded products.

- Various food product prototypes were developed using local crops (millet, cowpea, peanut butter) and the nutrient-rich crops (baobab flour or bouye, carrots and moringa), as well as vitamin and mineral mixes, including extruded naturally-fortified blends and weaning food formulations for Kenya and Senegal.
- A mapping exercise was done for qualitative and semi-quantitative descriptive analysis of commercial products to help optimize FPL product formulations for the Kenyan market. Results suggested that FPL instant products were very similar in product characteristics to those non-instant fortified composite flour products present in the Kenya market. The FPL products have the advantages of being instant and of higher nutritional quality.
- Five variations of extruded instant cereal products developed at the University of Eldoret's FPTIC were submitted and certified for production by the national certifying body, Kenya Bureau of Standards (KEBS) (***Figure 10***). The FPTIC incubatee's brand label of fortified instant product is shown in ***Figure 11***.


*Figure 10*. Kenya Bureau of Standards certificate and sample of the certified FPL Product Concept


***Figure 11***. FPTIC Incubatee's brand label of fortified instant product

- Studies were conducted on the effects of extrusion on the shelf-life, sensory attributes, phytate reduction, and starch digestibility of pearl millet-based flours and porridges. The most favorable products were selected for a consumer market study be to done in Senegal. Extrusion resulted in: 1) Increased shelf-life, improved sensory attributes, and reduced phytates (anti-nutritional factors), and 2) Reduced *in vitro* starch digestibility in whole grain flour (compared to decorticated flours), which gives added benefits of slow starch digestibility and moderated glycemic response from the products.
  - Utilization of Outputs: Consumer test results supported the continued focus on instant extruded products.
- A study was conducted to determine optimum conditions for using the extruder in resource-limited conditions (mainly energy for extrusion and drying).
  - Utilization of Outputs: Results of this study were used to identify the optimum conditions for moisture content of the extrudates to lower extrusion and drying energy costs and drying time.
- Test formulations were made with blends of cereals and nutrient-dense plant materials (carrot, baobab, moringa) to create commercial versions of extruded products for the Senegal and Kenya markets. Nutritional analyses have been completed for those leveraging food-to-food fortification in Senegal and are pending in Kenya. The product for Kenya was used in a human stable isotope study, which is ongoing.
- A study on natural provitamin A fortification of sorghum flour with orange fleshed sweet potato showed that both conventionally cooked and extrusion cooked instant porridge can make a significant contribution to the vitamin A requirements of at-risk groups.

## Activity 2.4: Begin to evaluate nutritional impact of the program

***Overview of Specific Activities:***

- Executed a clinical trial in Kenya to assess method of increasing bioavailability of iron

***Accomplishments and Utilization of Outputs/Outcomes:***

- The clinical trial with ~20 participants started in late March 2019 at University of Eldoret, Kenya and at the University of Moi-AMPATH clinical unit to test iron bioavailability in nutrient-fortified flours with natural plant fortificants that are hypothesized to increase bioavailability.
  - Outcomes: The study was suspended by the Purdue's Institutional Review Board due to two incidences of "unexpected adverse events", which were: 1) two reports of nausea and diarrhea in the night following consumption of the test porridges, and 2) one incidence of vomiting during consumption of the test porridge. A request was made that the food preparation area be sanitized prior to further use, and at this time it was noted that a misunderstanding had occurred whereby the Purdue University PI (Hamaker) was not present during the time of the study protocol in Kenya, and the Purdue IRB had expected on-site oversight. This was even though co-PI Ferruzzi from NCSU was on-site. On completion of all reports, including to USAID, the group decided to re-instigate the study, with expected completion in next year of project.

# Objective 3: Strengthening institutional and human capacities among the actors along the value chains, with emphasis on gender sensitive approaches

## Activity 3.1: Train graduate students from US and focus countries

***Overview of Specific Activities:***

- Selected, enrolled, and trained graduate students from US and Africa (especially from Senegal and Kenya)

**Long-Term Training:**

| Name | Sex | University | Degree | Major | Program End Year | Degree Granted | Home Country |
|---|---|---|---|---|---|---|---|
| Rose Likoko | Female | Univ. Eldoret | MS | Food Science | 2019 | No | Kenya |
| Harriet N. Omutimba | Female | Pwani Univ. | PhD | Social Ethics & Gender | 2019 | No | Kenya |
| Fallou Sarr | Male | Cheikh Anta Diop Univ. | PhD | Food Science | 2019 | No | Senegal |
| Maty Diop | Female | Cheikh Anta Diop Univ. | PhD | Nutrition Science | 2019 | No | Senegal |
| Eliasse Diémé | Male | Cheikh Anta Diop Univ. | PhD | Food Sci. & Nutrition | 2019 | No | Senegal |
| Abdourahmane Diop | Male | Univ. Thiès | MS | Agricultural Economics | 2017 | No | Senegal |
| Adeoluwa Adetunji | Male | Univ. Pretoria | PhD | Food Science | 2015 | Yes | Nigeria |
| Nokuthula Vilakati | Female | Univ. Pretoria | PhD | Food Science | 2016 | Yes | South Africa |
| Oluyimika Adeotola | Female | Univ. Pretoria | PhD | Nutrition | 2019 | No | Nigeria |
| Isiguzoro Onyeoziri | Male | Univ. Pretoria | PhD | Food Science | 2019 | No | Nigeria |
| Adeyemi Adeyanju | Male | Univ. Pretoria | PhD | Food Science | 2019 | Yes | Nigeria |
| Renee van der Merwe | Female | Univ. Pretoria | MS | Nutrition | 2018 | Yes | South Africa |
| John Lubaale | Male | Univ. Pretoria | MS | Food Science | 2018 | Yes | Uganda |
| John Gwamba | Male | Univ. Pretoria | MS | Food Science | 2016 | Yes | Botswana |
| Rudu Maneya | Female | Univ. Pretoria | MS | Food Science | 2019 | No | South Africa |
| Tim Tubbs | Male | Purdue Univ. | MS | Plant Science | 2016 | Yes | USA |
| Brett Lane | Male | Purdue Univ. | MS | Plant Science | 2016 | Yes | USA |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pablo Cesar Torres-Aguilar | Male | Purdue Univ. | PhD | Food Science | 2019 | No | Ecuador |
| Hawi Debelo | Female | Purdue Univ. | PhD | Nutrition | 2018 | No | Ethiopia |
| Emmanuel Ayua | Male | Purdue Univ. | PhD | Food Science | 2020 | No | Kenya |
| Cheikh Ndiaye | Male | Purdue Univ. | PhD | Food Science | 2018 | Yes | Kenya |
| Ravindra Shrestha | Male | Purdue Univ. | MS | Agric. & Biological Engineering | 2017 | Yes | Nepal |
| Mingyuan Chen | Female | Purdue Univ. | MS | Agricultural & Biological Engineering | 2019 | No | China |
| Hira Channa | Female | Purdue Univ. | PhD | Agricultural Economics | 2019 | No | Pakistan |
| Amanda Fuller | Female | Purdue Univ. | MS | Agricultural Economics | 2019 | No | USA |
| Laura Leavens | Female | Purdue Univ. | MS | Agricultural Economics | 2020 | No | USA |
| Sharon Wanjiru Kinyungu | Female | Purdue Univ. | MS | Agricultural Economics | 2019 | No | Kenya |
| Stacy Prieto (McCoy) | Female | Purdue Univ. | PhD | Agricultural Economics | 2018 | Yes | USA |
| Emmaculate Sanya | Female | University of nairobi | MS | Food Quality and Safety | 2020 | No | Kenya |

***Summary of long-term training:***

| Country | Male | Female | Total |
|---|---|---|---|
| U.S.A. | 2 | 2 | 4 |
| Africa | 10 | 10 | 20 |
| Other | 2 | 2 | 4 |

***Special Notes about Students Trained:***

Cheikh Ndiaye became the Lead PI at ITA in Senegal after completing his Ph.D. work.

## Activity 3.2: Provide training for collaborators

***Overview of Specific Activities:***

- Trained FPL collaborators and students on:
  - Methodology and technologies important for project
  - Best practices in scaling agricultural technologies in developing countries (via Scale Up Conference organized by Suzanne Nielsen; held at Purdue on Sept. 25-27, 2018; over 200 attendees from over 90

organizations and 21 countries, representing researchers, business, non-governmental organizations (NGOs), and donor groups)

**Short-Term Training of Students and Collaborators:**

| Country of Training | Brief Purpose of Training | Who was Trained[1] | Number Trained[2] M | F | Total |
|---|---|---|---|---|---|
| Senegal (ITA) | Training on concept of Incubation Center | Dr. Violet Mugalavai, Univ. Eldoret, Kenya; | | 1 | 1 |
| South Africa (University of Pretoria) | Sensory evaluation training: descriptive and affective hedonic test methods and statistical analysis | Dr. Violet Mugalavai, University of Eldoret, Kenya; Dr. Djibril Traore and Mamadou Sadji, ITA. | 1 | 2 | 3 |
| South Africa (University of Pretoria) | Mineral bioaccessibility assay and design of sensory evaluation facilities | Dr. Cheikh Ndiaye, ITA | 1 | | |
| Kenya (University of Eldoret) | Use of the Bleach Test to identify sorghum grains with a pigmented testa to facilitate supply of grain of the required quality for processing: trained by Prof. Duodu of Pretoria | Graduate students | 2 | 2 | 4 |
| Senegal (ITA) | Proficient use of the extruder: trained by Salif Sow (who was previously trained by Dr. Amudhan Ponrajan from Purdue) | Student interns at ITA from Cheikh Anta Diop Univ. | 1 | 1 | 2 |
| USA (Purdue Univ.) | Training in mycotoxin analysis and techniques in molecular identification of fungi | Ms. Angeline Maina, Univ. Nairobi, Kenya | | 1 | 1 |
| USA (Purdue Univ.) | Design and testing of cabinet solar dryer | Visiting undergraduate student from Universidad Nacional de Columbia and visiting graduate from Earth Univ., Haiti | 1 | 1 | 2 |
| USA (Purdue Univ.) | Cabinet solar dryer design | Purdue Univ. Discovery Park Undergraduate Research Interns | 2 | | 2 |
| USA (Purdue Univ.) | Preliminary testing of the solar wrap dryer prototypes | Undergraduate students from Purdue Agricultural and Biological Engineering | 1 | 1 | 2 |
| USA (Purdue Univ.) | Scale Up Conference: Best practices in scaling technologies | Investigators involved in FPL project, including Purdue faculty, Dr.Violet Mugalavai (Univ. Eldoret), and Patrick Ketiem (KALRO), and graduate students | 5 | 4 | 9 |
| USA (Purdue Univ.) | In-depth review and refresher course on starch fundamentals | Dr. Violet Mugalavai (Univ. Eldoret) | | 1 | 1 |

***Results of Training Activities:***

Training involved improved their abilities of collaborators and students involved in the project to enhance their performance.

## Activity 3.3: Conduct workshops/training sessions for extension agents, farmers, traders, and processors on developed technologies

***Overview of Specific Activities:***

Drying & Storage:

- Incorporated data from baseline survey into capacity building efforts in training extension agents in Senegal, Kenya and other countries in Africa
- Did on-station and on-farm demonstrations in Kenya and Senegal of grain drying technology for farmers, extension staff, NGOs, grain traders, and others related to drying and storage technologies (with emphasis on women and youth):
    - Sought their input early in technology development process, then sought feedback on technologies proposed/developed
    - Trained on promising technologies, especially the hygrometer
    - Worked with Bell Industries to train larger-scale farmers and traders in Kenya, and to identify venders for hygrometers in Kenya
    - Identified potential manufactures of PICS bags in Senegal, and attempted to establish license agreement; Identified and established distributor and vender of PICS bags and hygrometers in Kolda region of Senegal
    - Ensured that hygrometers and PICS bags were available of sale at demonstrations
    - Conducted training of trainers in Kenya and Senegal

Processing & Nutrition:

- Initiated development of Incubation Center training programs and technology dissemination plan
- Worked with entrepreneur in Touba, Senegal as a model for disseminating extrusion technology, explored scaling-up of millet processing to other regions
- Used new Incubation Center at University of Eldoret for training of youth entrepreneur processors, women's groups, and university students
- Conducted workshops for entrepreneur processors at ITA, Senegal and University of Eldoret, Kenya on how to create successful processing enterprises

***Accomplishments and Utilization of Output/Outcomes:***

Drying & Storage:

- In initial train-the-trainer workshops on grain post-harvest practices (for extension staff, service providers, and researchers):
    - Presented results of survey on maize post-harvest practices done in previous year
    - Training focused on economic importance of aflatoxin, best post-harvest practices for maize, appropriate drying practices, low-cost moisture measurement methods, and storage with PICS bags
    - Obtained feedback from attendees on FPL developed/proposed technologies

- In later train-the-trainer workshops on grain post-harvest practices, training focused on best management practices for drying and storing grain, knowledge about aflatoxin contamination in grain, its health effects and prevention through best post-harvest management practices, and the demonstration and use of technologies developed under the project (i.e., hygrometer method for maize moisture determination, PICS bag storage method, use of solar dryers). Extension activities were done in both Senegal and Kenya on the hygrometer, solar dryers (FPL-generated), and hermetic storage bags. Over 2000 farmers and traders were trained on these technologies and other post-harvest handling practices. In Senegal, Purdue partnered with ISRA (FPL local collaborator), and two local extension agencies (SEDAB and ANCAR) to conduct trainings. COFISAC/FUMOA, a local company that manufactures bags, has been in talks with Purdue Global to obtain a license for manufacturing PICS bags. The local company will also market hygrometers.

Processing & Nutrition:

- ITA built expertise and capacity at women-directed Dakar food processing enterprises and conducted training at Mme. Mbacke's processing unit in Touba, Senegal
- Univ. Eldoret FPTIC incubator
    - Trained processors on extrusion and other processing methods
    - Participated in public exhibitions and demonstrations on how to make thick and thin porridges using instant flours (1000 participants attended the demonstrations at the Annual Agribusiness Trade Fair).
        - Outcome: Increased public interest in instant flours (with and without fortification)

**Training of Farmers, Traders, Agricultural Extension Agents, Technicians, and Food Processors**

| **Country of Training** | **Brief Purpose of Training** | **Who was Trained**[3] | **Number Trained**[4] **M** | **F** | **Total** |
|---|---|---|---|---|---|
| ***Drying & Storage*** | | | | | |
| ***2016-2017*** | | | | | |
| Senegal | Proper post-harvest practices | Farmers | | | 1611 |
| Senegal | Proper post-harvest practices | Farmers and youth (576 youth) | 1903 | 1327 | 3806 |
| | | | | | |
| ***2017-2018*** | | | | | |
| Kenya | Proper post-harvest practices | Grain traders & County extension workers | 94 | 73 | 167 |
| Kenya | Proper post-harvest practices | Farmers | | | 589 |
| Kenya | Proper post-harvest practices | Farmers | | | 1198 |
| Kenya | Proper post-harvest practices | Farmers (300) & traders (300) | | | 600 |
| Kenya | Proper post-harvest practices | Extension staff | | | 12 |
| Senegal | Proper post-harvest practices | Farmers | 762 | 411 | 1173 |
| Senegal | Proper post-harvest practices | Farmers | | | 337 |
| Senegal | Proper post-harvest practices | Farmers | | | 45 |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| ***2018-2019*** | | | | | |
| Kenya | Drying and storage, and moisture detection service | Traders in Uasin Gishu; Farmers – Field Day Exhibition; Extension training, Nandi Co. | 486 | 349 | 817 |
| Senegal | Drying and storage technol. | Trainers | 12 | 2 | 14 |
| ***Senegal*** | Drying and storage technol. | Farmers | 1736 | 887 | 2663 |
| ***Senegal*** | Aflatoxin analysis | Technicians | 6 | 2 | 8 |
| | | | | | |
| ***Total for Drying & Storage*** | | | | | 13,040 |
| | | | | | |
| ***Processing & Nutrition*** | | | | | |
| ***2016-2017*** | | | | | |
| Kenya, Univ. Eldoret | Extrusion and other processing methods | Processors from Eldoret area | 12 | 29 | 41 |
| Kenya, Univ. Eldoret | Cereal processor training (done with SMART FOODS PROJECT of ICRISAT) | Cereal processors in Eldoret area | 0 | 16 | 16 |
| | | | | | |
| ***2017-2018*** | | | | | |
| Kenya, Univ. Eldoret | Cereal processing and natural fortification | Youth | 7 | 34 | 41 |
| Kenya, Univ. Eldoret | Cereal processing and natural fortification | Youth Incubatees | 3 | 7 | 10 |
| Senegal, Touba | Workshop on extrusion technology (conducted at Mme. Mbacke's Touba Darou Salam Processing Unit) | Processors from Diourbel region's platform and representatives from the other 3 regional processor platforms | 12 | 28 | 40 |
| | | | | | |
| ***2018-2019*** | | | | | |
| Kenya, Univ. of Eldoret | Entrepreneurship and food processing and nutrition | Students and youth | 84 | 39 | 123 |
| | | | | | |
| **Total for Processing & Nutrition** | | | | | 271 |
| **Total for Project** | | | | | 13,311 |

**Notes about FPL Participation in Scale Up Conference, Sept. 25-27, 2018:**

- Promising FPL technologies were displayed including the hygrometer, DEHYTRAY (a multipurpose solar dehydration tray), and instant fortified cereal flour formulations. Dr. Mugalavai presented a poster on "Technology-Based Incubation Centre for Developing Affordable Nutritious Foods: Scaling up of Food Processing Training and Incubation Centre Technologies".
- Two innovations associated with FPL project were assessed by teams of scaling experts: hygrometer and "Hub and Spoke" food innovation system. The goal of the assessment was to obtain feedback regarding key strengths and weaknesses relative to readiness of the innovation for scale up and to provide suggestions for scalable pathways. The assessment involved a short presentation on the technology or innovation by the principal investigators, followed by a three-member expert panel asking clarifying questions and providing feedback on ways to boost the innovations for scale-up. Overall, the feedback received was very useful including evaluation of key strengths and weaknesses relative to readiness of the innovation for scale-up and suggestions for scalable pathways. We plan to incorporate this feedback in our scaling efforts. The following is a brief description of the two innovations assessed and the feedback received.

1) Hygrometer-based method for measuring moisture content of grains.

Description: The method is based on a low-cost Mini Digital Hygrometer that gives a temperature/relative humidity reading. Equilibrium RH of 65% at temperature of 20-30C indicates a moisture content of 12.5 to 13.5% (15-20 min). The hygrometer retails for <$2.00 in the USA. Purdue, CIMMYT, and KALRO have partnered with Bell Industries, a local company in Kenya, to test market the sale of hygrometers in East Africa.

Feedback: The hygrometer is positioned as a technology to address economic issues (trading in grains) and safety issue (mitigation of aflatoxin)

a) The commercial argument of paring it up/ complementing with the PICS bags as a complimentary technology to assess the moisture before storage is plausible and more likely to get traction. It is difficult to make a business case for just hygrometers alone due to the low profit margin.
b) When pairing with PICS bags (which are already doing well in the market), make sure not to compromise the value proposition of the bags by adding an innovation that may not work well e.g. battery malfunction
c) There is need to balance supply and demand to avoid market collapse before it even starts. The commercialization plan should ensure import and custom clearing are fast enough or have a business willing to stock an inventory including the batteries to avoid the following scenarios: 1) Creating a demand that cannot be satisfied, and 2) Loading too much on distributors that they cannot sell.

2) The "Hub and Spoke" Food Innovation System for disseminating of food processing and nutrition technologies and strengthening food processing businesses.

Description: The "Hub" is a central food technology-based facility housed at a local institution (National Agriculture Research Centers, NARS or universities).

a. The "Hub" provides various functions including R&D, training, and technical support for entrepreneur processors.
b. The "Spokes" are business units that make and sell products. They can be women associations or youth groups, principally in rural communities, or individual processors in urban areas. They process using technologies and formulations developed at the Hubs, but also innovate themselves (e.g. bring new product concept ideas for R&D)

Feedback:

a) Hub is performing a number of functions, thus should not be looked at as a single unit, but rather need to tease out the roles in order to establish units/institutional structures; the most apparent are:

1. Public Community-serving Unit that is funded by the government for the greater good e.g. to provide R&D and training functions
2. Private Unit for income generation to serve as launch pad for food processors (acts as a traditional incubator/accelerator). If successful will drive scale and sustainability
    i. Can start as a public private partnership and over time become a revenue generator if successful will help the business scale-up and become sustainable
    ii. Crowd in private investors
    iii. Position it for impact investing

b) Clearly define the development outcomes e.g. nutrition, enterprise building, to clarify mission and give a path to scale.
    1. Team is currently on track with all three FTF goals of improved nutrition, economic growth (improved household incomes), and resilience (social capital).
    2. There is a case to make to a donor like USAID to ramp-up the system to other countries or broadly within same country
    3. Technology and business skills combined make a strong case for social impact investment

# Objective 4: Establish and strengthen public-private partnerships to promote technology innovation and adoption

## Activity 4.1: Strengthen established public-private partnerships

***Overview of Specific Activities:***

Overall:

- Identified and visited local businesses with interest in post-harvest issues
- Identified and contacted USA and multi-national businesses with interest in post-harvest

Drying & Storage:

- Incorporated data from baseline survey into capacity building efforts in training extension agents in Senegal, Kenya and other countries in Africa
- Linked with A to Z Textiles on testing hermetic storage bags; Incorporate the A to Z Textile hermetic bags in the on-station and on-field demonstrations
- Worked with Bell Industries on testing and dissemination of hygrometers and moisture measuring strips; Focus on distribution network to recruit venders and get technologies into rural areas
- Engaged with county and national government on hygrometer and hermetic bags to make national policy to support extension in Kenya
- Supported COFISAC and SEDAB commercializing PICS bags and hygrometers in Senegal; focus on distribution network to recruit venders and get technologies into rural areas

Processing & Nutrition:

- Officially transferred extrusion technology to Mme. Mbacke's processing facility in Touba, Senegal, at a ceremony (~500 attendees) involving local and national leaders

- Worked to expand processing business in Touba, Senegal and start-ups in Eldoret, Kenya

***Accomplishments and Utilization of Output/Outcomes:***

Drying & Storage:

- Partnered with Bell Industries, a local company in Kenya, to test market the sale of hygrometers in the East Africa region.
- Signed an agreement with Global Good to develop and later to evaluate protocols that use inexpensive new generation humidity/temperature devices to measure grain moisture.
- Held meeting with hermetic bag partners to discuss results of aflatoxin and storage results
    - Outcomes: Hygrometers are currently being sold on the local market in Kenya and Senegal. Global Good is working to develop a better hygrometer.
- Commercialization:
    - FPL investigator, Klein Ileleji, commercialized his multi-purpose solar drying technology through his start-up company, JUA Technologies International LLC. He worked with Purdue University Foundry, a university business incubator, to develop a business and commercialization plan.
        - DEHYTRAY™ – multipurpose solar drying tray
        - DEHYMELEON™ – multipurpose solar cabinet dryer
- The DEHYTRAY™ was awarded a 2019 AE50 award for innovation in agricultural engineering equipment design by the American Society of Agricultural and Biological Engineers, and was a finalist in the 2019 world changing ideas awarded by Fast Company.
- 
    - FPL partnered with PICS to add a plastic jar to the hygrometer to make it a more standardized product
        - Outcomes: We are testing the POD dryer and JUA Technologies is selling the DEHYTRAY and the DEHYMELEON. We will track sales of these products in the next phase of FPL.

Processing & Nutrition:

- Partnered with various public and private entities at the University of Eldoret as follows: 1) to supply ingredients for product development (Organi Ltd., Kisii County; Nyapalo Farmers' Cooperative, Homabay County; AWRICO Health Millers, Bungoma County and grain farmers from Busia County, Uasin Gishu, and Elgeyo Marakwet Counties; 2) to provide technical support on natural fortification (International Potato Center, CIP in Nairobi, Kenya; and 3) training of processor in partnership with ICRISAT.
    - Outcomes: These activities have increased the visibility of the FPTIC incubator and established it as a viable training partner for local industry and development organizations.
- ITA strengthened the partnership with Darou Salam Cereal Processing Unit owned by Mme. Mbacke, a key local partner in Touba. Extrusion technology was officially transferred to Mme. Mbacke processing facility in Touba, Senegal, at a ceremony (~500 attendees) involving local and national leaders.
    - Outcomes: Event helped increase project's visibility with the Senegal government and with others interested in processing and entrepreneurship. Soon after the extruder transfer to Touba, Senegal government officials expressed interest in the FPL project. The government provided inputs to farmers in the region to increase millet production. Mme Mbacke received contracts from government officials to supply instant flour for nutrition initiative in Senegal

# Activity 4.2: Explore new synergistic partnerships with other FtF Labs and complementary USAID projects in the USA and Sub-Saharan Africa (SSA).

***Overview of Specific Activities:***

- Initiated/continued conversations with organization who participated in the post-harvest arena
- Initiated/continued conversations other FTF Innovation Labs
- Explored links with ACDI/VOCA to measure commercialization of cob-fueled dryer potential in Kenya
- Investigated opportunities to work with USAID Senegal funded project on Youth in Agriculture to engage youth to be service providers for FPL technologies in Senegal
- Partnered with the Senegalese government, World Food Programme, and CLUSA (NGO) to scale-up rural processing of fortified instant products in Senegal

***Accomplishments and Utilization of Output/Outcomes:***

Drying & Storage:

- We conducted a study with the Horticulture Innovation lab to measure demand for the hygrometer and DryCard in Western Kenya in 2017.
- We will continue to work with interested partners to train people on best practices for drying and storage and to promote improved post-harvest technologies.
- Will work with interested partners to train youth and women on drying and storage practices and technologies. We will recruit interested women and youth to sell these technologies in rural areas and bridge the last mile of the supply chain.

Processing & Nutrition:

- A partnership evolved between FPL and SMIL processing projects, whereby development of nutritionally enhanced formulations, including locally-sourced micronutrient-rich plant materials as fortificants for regular and instant flour blends, for SMIL were supported by research done by FPL. This resulted in formulations used in the SMIL Niger program for rural processing sites that were consumer preference tested.

# FURTHER CHALLENGES AND OPPORTUNITIES

**Drying & Storage**

- **Challenges:**
  - Getting farmers and other to value quality, when they cannot visually see it (e.g., aflatoxin presence) and when most buyers in rural markets will not pay a premium for higher quality.
  - Drying of low value grains such as maize continues to be a challenge. Difficult for a solar or other mechanical dryer to be more cost-effective than solar drying on a tarp or other clean surface. Most smallholder maize farmers are not at scale of production to invest in solar or other mechanical dryer
  - Scale up:
    - How to get technologies to those who really need it
    - Reaching people at the “last mile”
    - Engaging women and youth group to sell post-harvest inputs.
- **Opportunities:**
  - Expanding effort beyond just cereals, to new crops (e.g., grain legumes)
  - Reaching new populations of farmers and traders in new areas of Kenya and Senegal
  - Develop sustainable supply chains where rural women and youth can sell post-harvest inputs as a business.

**Processing & Nutrition**

- **Challenges:**
  - Scaling up to reach more people through existing and new Food Processing Innovation Centers
  - Achieve and document nutritional status improvement through our market-led nutrition approach
- **Opportunities:**
  - Reaching more people by scaling up efforts of individual “Spoke” Food Processing Innovation Centers, and expanding with more “Hub” Innovation Centers
  - Have a positive effect on nutritional status of populations through marketing of nutritionally-enhanced products formulated for local populations
  - Increasing the number of entrepreneurs through training at Innovation Centers
  - Increasing for farmers the markets for their local crops

# PROPOSED FUTURE ACTIVITIES FOLLOWING PHASE I RESEARCH ACCOMPLISHMENTS

**Objective 1: Drying & Storage**

| **Objective 1**: Improve drying and storage of cereals and grain legumes in the humid tropics of Africa (focus in Senegal and Kenya) |
|---|
| **Activity 1.1:** Train farmer and traders on best practices for harvesting, drying and storage, using most cost-effective moisture testing, drying, and storage technologies<br><br>**Activity 1.2:** Work with private-sector in Kenya and Senegal to scale up most cost-effective moisture testing, drying, and storage technologies<br><br>**Activity 1.3:** Assess effect of pre-harvest and post-harvest interventions to reduce aflatoxin in maize (in Kenya) |

**Objective 2: Processing & Nutrition**

| **Objective 2**: Drive the value-chain through processing to increase commercialization and improve nutrition (focus in Senegal and Kenya) |
|---|
| **Activity 2.1:** Increase availability and market share of safe high-quality and market competitive cereal and legume-based products in the marketplace (rural and urban).<br><br>**Activity 2.2:** Make sustainable in the marketplace nutrient-enhanced products that utilize local commodities, and increase access to shortfall micronutrients to at-risk groups.<br><br>**Activity 2.3:** Establish innovative platform for delivery of successful food technologies (products and processes)<br><br>**Activity 2.4:** Improve market outlets and access for farmers |

# SUMMARY DATA ON FTF INDICATORS

| Regular Indicators | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|
| FTF Indicator 4.5 (10) (also called EG.2-x10) (dropped after 2018): Total increase in installed storage capacity ($m^3$) | 0 | 0 | 0 | 665 | 486 | Discontinued |
| FTF Indicator 2.5.2 (13) (also called EG.3-1) (dropped after 2018): Number of rural households benefiting directly from USG interventions | 0 | 40 | 30-new<br>40-cont.<br>70-total (urban) | 2291-new<br>70-cont.<br>2191-rural<br>170-urban<br>2361-total | 2813-new<br>3861-cont.<br>6334-rural<br>340-urban<br>6674-total | Discontinued |
| FTF Indicator EG.3-2 (New in 2018; Combines 3-1 and 3.2.1): Number of individuals participating in USG food security programs | 0 | 0 | 0 | 0 | 12,931 - total | 3542 - total |
| FTF Indicator 4.5.2 (5): Number of farmers and others who have applied improved technologies or management practices as a result of USG assistance | 0 | 0 | 0-drying & storage<br>7-value added/proc. | 0 | 0 | 3625 (number of persons trained; at present, cannot confirm application of technologies learned) |
| FTF Indicator EG.3.2-7 (New in 2018): Number of technologies, approaches, under various phases of research, development, and uptake as a result of USG assistance | 0 | 0 | 0 | 0 | 4-phase 3<br>6-phase 2<br>10-total | 1-phase 4<br>6-phase 3<br>3-phase 2<br>10-total |

| ***Capacity Building Indicators:*** | **2014** | **2015** | **201** | **2017** | **2018** | **2019** |
|---|---|---|---|---|---|---|
| FTF Indicator 4.5.2 (6) (also called EG.3.2.1) (dropped after 2018): Number of individuals who have received USG supported long-term agricultural sector productivity or food security training | 7-male<br>3-female<br>10-total (all new)<br>(3-U.S.<br>2-Kenya<br>0-Seneegal<br>5-other) | 9-male<br>6-female<br>15-total<br>(2-new;<br>13-cont.) | 15-male<br>7-female<br>22-total<br>(7-new;<br>15-cont.) | 15-male<br>8-female<br>23-total<br>(1-new;<br>22-cont.) | | Discontinued |
| FTF Indicator 4.5.2 (7) (also called EG.3.2-1) (dropped after 2018): Number of individuals who have received USG supported short-term agricultural sector productivity or food security training | 15-male<br>23-female<br>40-total<br>(all production) | | 67-gov't<br>46-private<br>25-civil soc.<br>138-total | 2191-production<br>82-private<br>(19-male<br>63-female)<br>46-civil soc.<br>(16-male<br>30-female)<br>2191-total | 156-total | Discontinued |
| FTF Indicator EG.3.2-2 (New in 2018): Number of individuals who have received USG-supported degree-granting non-nutrition-related food security training | | | | | 5-male<br>9-female<br>14-total | 4-male<br>9-female<br>13-total |
| FTF Indicator HL.9-4 (New in 2018): Number of individuals receiving nutrition-related professional training through USG-supported programs | | | | | 2-male<br>2-female<br>4-total | 1-male<br>2-female<br>3-total |

| *Partnership Indicator:* | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|
| FTF Indicator 4.5.2 (11) (dropped after 2018): Number of food security private enterprises (for profit), producers organizations, water user associations, women's groups, trade and business associations, and community-based organizations receiving USG assistance | 0 | 3-new, women's group | 7-new, private | 2-private<br>1-women's group<br>3-total (all new) | | Discontinued |
| FTF Indicator EG.3.2-4 (dropped after 2018): Number of for-profit private enterprises , producers organizations, water users associations, women's groups, trade and business associations, and community-based organizations receiving USG food security related organizational development assistance | | | | | 18-private<br>4-women's group<br>22-total | Discontinued |

# LIST OF REFEREED PUBLICATIONS, PRESENTATIONS, AND ABSTRACTS

**Year 5: October 1, 2018 to May 2019**

**Referred Publications:**

Adetola, O.Y., Kruger, J., White, Z., Taylor, J.R.N. 2019. Comparison between food-to-food fortification of pearl millet porridge with oringa leaves and baobab fruit and with adding ascorbic and citric acid on iron, zinc and other mineral bioaccessibility. LWT Food Science and Technology, 106:92-97.

Adeyanju, A.A., Kruger, J., Taylor, J.R.N., Duodu, K.G. 2019. Effects of different souring methods on the protein quality and iron and zinc bioaccessibilities of non-alcoholic beverages from sorghum and amaranth. Intl. J. of Food, Science + Technology, 54:798-809.

Channa H., Chen, A.Z., Pina, P., Ricker-Gilbert, J., Stein, D. 2019. What drives smallholder farmers' willingness to pay for a new farm technology? Evidence from an experimental auction in Kenya. Food Policy – in press.

Debelo, H., Ndiaye, C., Kruger, J., Taylor, J.R.N., Hamaker, B., Ferruzzi, M.G. 2019. African Adansonia digitate (baobab) modifies bioaccessibility but not intestinal uptake of provitamin A carotenoids from composite fruit, vegetable and millet porridges as assessed by in-vitro digestion coupled with Caco-2 cell culture model. Journal of Food Science and Technology (in review).

Nkhata, S.G., Ortiz, D., Baributsa, D., Hamaker, B.R., Rocheford, T.R., Ferruzzi, M.G. 2019. Assessment of oxygen sequestration on effectiveness of Purdue Improved Crop Storage (PICS) bags in reducing carotenoid degradation during post-harvest storage of two biofortified orange maize genotypes. Journal of Cereal Science 87, 68-77.

Van der Merwe, R., Kruger, J., Ferruzzi, M.G., Duodu, K.G., Taylor, J.R.N. 2019. Improving iron and zinc bioaccessibility through food-to-food fortification of pearl millet with tropical plant foodstuffs (moringa leaf powder, roselle calyces and baobab fruit pulp). J. Food Sci. Technol. 56, 2244-2256.

**Presentations:**

Dieme, E., Ndiaye, C., Traore, D., Sarr, I., Woloshuk, C.P. 2018. Managing aflatoxin contents in cereals and their byproducts in Senegal. Presentation Doctorial meeting at Cheikh Anta Diop University, Dakar, Senegal.

Prieto, S., Ricker-Gilbert, J., Bauchet, J., Sall, M. 2018. Incomplete information and product quality in rural markets: Evidence from an experimental auction for maize in Senegal. Department of Applied Economics, University of Minnesota, November 2018.

Prieto, S., Ricker-Gilbert, J., Bauchet, J., Sall, M. 2019. Incomplete information and product quality in rural markets: Evidence from an experimental auction for maize in Senegal. Department of Economics, Stellenbosch University, South Africa, February 2019.

Taylor, J.R.N. 2019. Natural Fortified SMART Foods: An Opportunity for SME Food Processing Entrepreneurs. University of Mauritius, Mauritius, June 2019.

**Other:**
Small Scale Food Processing Manual. 2018. University of Eldoret, Eldoret, Kenya

**Year 4: October 1, 2017 to September 30, 2018**

**Refereed Publications:**
Lane, B., Sharma, S., Niu, C., Maina, A.W., Wagacha, J.M., Bluhm, B.H., Woloshuk C. P. 2018. Changes in the fungal microbiome of maize during hermetic storage in the United States and Kenya. Frontiers in Microbiology 9:2336. doi: 10.3389/fmicb.2018.02336.

Ortiz, D, Ponrajan, A, Bonnet, JP, Rocheford, T, Ferruzzi, MG. 2018. Carotenoid stability during dry milling, storage, and extrusion processing of biofortified maize genotypes. J Agric Food Chem. 2018, 66:4683-4691. DOI: 10.1021/acs.jafc.7b05706.

Prieto, S., Ricker-Gilbert, J., Bauchet, J., & Sall, M. 2018. (revise and resubmit). Incomplete information and product quality in rural markets: Evidence from an experimental auction for maize in Senegal. Economic Development and Cultural Change.

Prieto, S., Bauchet, J., & Ricker-Gilbert, J. 2018. (under review). Do improved drying and storage practices reduce aflatoxins contamination in stored maize? Experimental evidence from smallholders in southern Senegal. Journal of Human Resources.

**Presentations:**
Adeyanju, A.A., Taylor, J.R.N., Kruger, J., and Duodu, K.G. 2018. Effects of different souring methods on phytate reduction and in vitro iron and zinc bioaccessibility in non-alcoholic beverages from sorghum, amaranth and their composite flour. Poster presentation, International Sorghum Conference, Cape Town, South Africa, 9-12 April 2018.

Adetola, A.I., Kruger, J., White, Z. and Taylor, J.R.N. 2018. Natural food fortification: A sustainable plant-based strategy to improve essential mineral bioavailability in African cereal-based diet. Poster presentation, South African Nutrition Congress, Johannesburg, South Africa, 5-7 September 2018

Adetola, A.I., Kruger, J., White, Z. and Taylor, J.R.N. 2018. Natural food fortification: A potential sustainable plant food-based strategy to improve essential mineral bioavailability in African cereal-based diets. Poster presentation, International Sorghum Conference, Cape Town, South Africa, 9-12 April 2018.

Channa, H., Ricker-Gilbert, J., DeGroote, H., Bauchet, J., Marenya, P. 2018. Willingness to pay for a new farm technology given risk preferences. Presentation at IAAE Triennial Conference, Vancouver, BC, Canada, July 28-August 2, 2018.

Chen, M., Stroshine, R.L., Raman, A., and Ketiem, P. 2018. Pico solar crop dryer (POD) for farm level grain drying by smallholder farmers in Africa. Paper 2018-01427 presented at the ASABE annual meeting, Detroit, MI, July 29 – August 1, 2018.

De Groote. H., Mugalavai, V., Ferruzzi, M., Onkware, A., Ayua, E., Duodu, K.G., Ndegwa, N., Hamaker, B.R. 2017. Consumer acceptance and willingness to pay for instant fortified cereal products in Eldoret, Kenya, Poster presentation, Sorghum in the 21st Century, Cape Town, South Africa, April 9-12, 2018.

Debelo, H.A., Ndiaye, C., Hamaker, B., Ferruzzi, M. 2018. African Adansonia digitate L. (baobab) modifies provitamin A carotenoid delivery from blended millet products as assessed by a coupled In vitro digestion Caco-2 cell model (P12-015). Nutrition & Health Conference 2018, April 30-May 2, 2018, Boston, MA.

Kinyungu, S. 2018.Efficacy of pre-harvest *Aspergillus flavus* biocontrol treatment on reducing aflatoxin accumulation during drying. Poster presentation 2nd African Symposium on Mycotoxicology, Mombasa, Kenya, June 24-27, 2018.

Lubaale, J., Taylor, J.R.N. and Duodu, K.G. 2018. Effects of fermentation and lactic acid acidification on phenolic content, antioxidant properties and protein quality of finger millet gruel. Poster presentation, International Sorghum Conference, Cape Town, South Africa, 9-12 April 2018.

Maneya, R. and Duodu, K.G. 2018. Effect of extrusion cooking on phenolic content, antioxidant properties and beta-carotene bioaccessibility of sorghum porridge fortified with orange flesh sweet potato flour. Poster presentation, International Sorghum Conference, Cape Town, South Africa, 9-12 April 2018

McCoy, S., Ricker-Gilbert, J., Bauchet, J. 2017. How do low-cost moisture detection devices influence aflatoxin spread? Evidence from smallholder households in Senegal. Agricultural & Applied Economics Association Annual Meeting. Chicago, IL, August 2017.

Mugalavai, V., Onkware, A., Bugusu, B., Hamaker, B., Ferruzzi, M. 2018, Technology-based incubation centre for developing affordable nutritious foods: Scaling up of food processing training and incubation centre technologies". Poster presentation at Scale-UP Conference, Purdue University, September 25-27, 2018.

Nkhata, S.G., Ortiz, D., Baributsa, D., Hamaker, B., Rocheford T., Ferruzzi, M.G. 2018. Reducing carotenoid degradation is key to maintaining nutritional quality of high carotenoid biofortified maize during storage (P03-007). Nutrition & Health Conference 2018, April 30-May 2, 2018, Boston, MA.

Onyeoziri, I., Taylor, J.R.N. and De Kock, H.L. 2018. Optimisation of extrusion cooking conditions to produce an instant wholegrain pearl millet porridge product. Poster presentation, International Sorghum Conference, Cape Town, South Africa, 9-12 April 2018.

Prieto, S., Bauchet, J., Ricker-Gilbert, J. 2018. Do improved drying and storage practices reduce aflatoxin contamination in stored maize? Experimental evidence from smallholders in southern Senegal, Presentation at IAAE Triennial Conference, Vancouver, BC, Canada, July 28 – August 2, 2018.

Ricker-Gilbert, J. 2018. What do we know about post-harvest quantity and quality losses in developing countries? Presentation at IAAE Triennial Conference, Vancouver, BC, Canada, July 28- August 2, 2018.

Van der Merwe, R., Kruger, J. and Taylor J.R.N. 2018. Food-to-food fortification of pearl millet porridge with local African plant foodstuffs can increase iron and zinc bioaccessibilities. Poster presentation, International Sorghum Conference, Cape Town, South Africa, 9-12 April 2018.

Van der Merwe, R., Taylor, J.R.N. and Kruger J. 2017. Food-to-food fortification of pearl millet instant porridge to increase iron and zinc nutritive values. Poster presentation International Union of Nutritional Sciences Congress, Buenos Aires, October 2017.

Woloshuk, C. 2018. The role of hermetic storage for postharvest mycotoxin control. Presentation at the World Mycotoxin Forum, Amsterdam, Netherlands, March 12-14, 2018.

**Conference Abstracts:**

Ndiaye, C., Martínez, M.M., Debelo, H., Hamaker, B.R., Campanella, O., Ferruzzi, G.M. 2018. Application of low cost extrusion in development of nutritionally enhanced instant millet-fruit blended porridges for West Africa. (Submitted to Global Sorghum Conference 2018).

Ketiem, P.K., De Groote, H., Ileleji, K.E., Ricker-Gilbert, J. Woloshuk, C., Raman, A., Stroshine, R., Bugusu, B.A. 2018. Managing grain post-harvest losses: a case study of solar drying and moisture detection devices in Western Kenya. Abstract submitted for oral presentation at Egerton University 12th International Conference (Kenya), March 28– 30, 2018.

**FPTIC/University of Eldoret Student Posters:**

Chebitok, V. 2018. Fortifying Irish potato with banana, amaranth, carrots and moringa.

Derick Musili, S. 2018. Fortification of sorghum flour: fortificants - butternut, amaranth and baobab.

Jelimo.B. 2018. Fortifying arrowroots flour with maize flour, cowpea flour and baobab flour.

Mutinda, V. 2018. Fortified rice flour concept with pumpkin, carrots, amaranth and baobab.

Orina Kerubo. B. 2018. Fortifying sorghum flour with cassava flour, ofsp flour, bambar nut flour and baobab flour.

Wanja, J. 2018. Fortifying sorghum flour with green banana flour, pumpkin flour and pumpkin seed flour.

**<u>Year 3: October 1, 2016 to September 30, 2017</u>**

**Refereed Publications:**

DeGroote, H., Kariuki, S.W., Traore, D., Taylor, J.R.N., Ferruzzi, M., Hamaker, B.R. 2017. Measuring consumers' interest in instant fortified pearl millet products: A field experiment in Touba, Senegal. Journal of the Science of Food and Agriculture, online: doi:10.1002/jsfa.8722.

Lane, B., Woloshuk, C.P. 2017. Impact of storage environment on the efficacy of hermetic storage bags. Journal of Stored Products Research. 72: 83-89.

Tubbs, T., Woloshuk, C.P., Ileleji, K.E. 2017. A simple low-cost method of determining whether it is safe to store maize. AIMS Agriculture and Food, 2:43-55. DOI: 10.3934/agrfood.2017.1.43

**Presentations:**

Ferruzzi M.G, Debelo, H., Ndiaye C., De Groote, H., Traore, D., Taylor, J.R.N., Bugusu, B., Hamaker, B.R. 2016. Leveraging native nutrient dense plants in development of market-led instant fortified grain foods. Presented at the Catholic Relief Services' Integrated Nutrition Conference, Nairobi, Kenya, November, 2016.

Lowenberg-DeBoer, J. 2017. Designing affordable grain dryers for on-farm use in Africa. Presented at the Post-harvest Congress in Nairobi, Kenya, March, 2017.

Mugalavai, V., Onkware, A., Ferruzzi, M.G., Debelo, H., Ndiaye, C., Traore, D., De Groote, H., Taylor, J.R.N., Duodu, G., Bugusu, B., Hamaker, B.R. 2017. Technology-based incubation centres for developing affordable nutritious foods. Presented at the Post-harvest Congress, Nairobi, Kenya, March, 2017.

Torres-Aguilar, P., Martínez, M.M., Hamaker, B.R. 2017. Impact of low-cost extrusion on lipid oxidation and acceptability of whole grain pearl millet (Pennisetum glaucum) flours. Institute of Food Technologists annual meeting, Las Vegas, NV, June 2017.

Van der Merwe, R., Taylor, J.R.N., Kruger, J. 2017. Mineral-rich plant foods has the potential to increase iron and zinc bioavailability from an instant cereal-based porridge. 3rd Hidden Hunger Conference. Stuttgart, Germany. March 2017.

Ileleji, K.E., R. Shrestha, I. Sarr, P. Diop, P. Ketiem, and H. De Groote. 2017. Field testing of a multipurpose solar dryer for small farmholders. First All African Postharvest Congress and Exhibition, Nairobi, Kenya, 28-31 March.

**Other:**
Shrestha, R. 2017. Development and testing of a multipurpose solar dryer for smallholder farmers corn (*Zea mais*) drying. M.S. Thesis.

**Year 2: October 1, 2015 – September 30, 2016**

**Refereed Publications:**
Kruger, J. 2016. Replacing electrolytic iron in a fortification-mix with NaFeEDTA increases both iron and zinc availabilities in traditional African maize porridges. Food Chemistry, 205, 9-13.

Minnis-Ndimba, R., Kruger, J., Taylor, J.R.N., Mtshali, C., Pineda-Vargas, C.A. 2015. Micro-PIXE mapping of mineral distribution in mature grain of two pearl millet cultivars. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 363, 177-182.

Ortiz, D, Rocheford T., Ferruzzi, MG. 2016. Influence of temperature and humidity on the stability of carotenoids in biofortified maize (Zea mays L.) genotypes during controlled postharvest storage. J Agric Food Chem. 2016 Apr 6;64(13):2727-36.

Tubbs, T., Baributsa, D., Woloshuk, C. 2016. Impact of opening hermetic storage bags on grain quality, fungal growth and aflatoxin accumulation. Journal of Storage Products Research 69, 276-281.

Vilakati, N., Taylor, J.R.N., MacIntyre, U., Kruger, J. 2016. Effects of processing and addition of a cowpea leaf relish on the iron and zinc nutritive value of a ready-to-eat sorghum-cowpea porridge aimed at young children. LWT-Food Science and Technology 73, 467-472.

**Presentations:**
Debelo, H., Ndiaye, C., Hamaker. B.R., Ferruzzi, M.G. 2016. Interactions between native African plant materials modify in vitro bioaccessibility of provitamin A carotenoids from blended cereal products. Presented at Experimental Biology, 2016. San Diego, CA.

Lane, B., Woloshuk, C. 2016. Assessment of hermetic storage of maize under different environmental conditions. Poster presentation at International Congress of Entomology. Orlando, FL, September 25-30, 2016.

Lane, B., Woloshuk, C. 2016. Assessment of hermetic storage of maize under different environmental conditions. American Phytopathological Society Annual Meeting, Tampa, FL, July 30- August 3, 2016.

McCoy S., Ricker-Gilbert J., Sall, M., Bauchet J. 2016. How do traders and consumers in sub-Saharan Africa value maize moisture content? Evidence from an experimental auction in Senegal. Presented at the Agricultural and Applied Economics Association Annual Meeting, Boston, Massachusetts, July 2016.

Ndiaye, C., Sarr, F., Traore, D., Sow, M.S., Hamaker, B.R., Ferruzzi, M. 2016. Impact of extrusion on fruit/vegetable-millet blends on recovery of provitamin A and product physical properties. Poster presentation at Institute of Food Technologists annual meeting, Chicago, IL, June, 2016 (received 1st place).

Ortiz, D., Rocheford, T., Ferruzzi, M.G. 2016. Influence of temperature and humidity on the stability of carotenoids in biofortified maize genotypes. Presented at Experimental Biology 2016. San Diego, CA.

Shrestha, R., Olasubulunmi, M., Ileleji, K., Woloshuk, C., Tubbs, T., DeGroote, H., Shitanda, D., Sarr, I., Samb, M. 2016. Assessing the drying technology needs from a survey of farmers' post-harvest practices in Kenya and Senegal. Poster presentation I2D Exposition held by Global Engineering Program, Purdue University, West Lafayette, Indiana, April 1, 2016.

**Other:**

Taylor, J.R.N., Kruger, J. 2016. Millets. In: The Encyclopedia of Food and Health vol. 3 (B. Caballero, P. Finglas, and F. Toldrá, eds.). Academic Press, Oxford, pp. 748-757.

**<u>Year 1: May 19, 2014 – September 30, 2015</u>**

**Presentations:**

Tubbs, T., Woloshuk, C. 2015. Simple devices for determining grain moisture, Abstract submitted for a poster presentation at the annual meeting of the American Phytopathological Society, Pasadena, California. August 2015.


FOR MORE INFORMATION CONTACT:

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