FEED THE FUTURE INNOVATION LAB FOR FOOD PROCESSING AND POST-HARVEST HANDLING

ANNUAL REPORT

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LEAD UNIVERSITY

Purdue University

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LIST OF COUNTRIES WHERE THE PROJECT WORKS

Kenya and Senegal

LIST OF PROGRAM PARTNERS[1]

- ***USA:*** North Carolina A&T State University and North Carolina State University
- ***Kenya:*** University of Eldoret; Kenya Agricultural and Livestock Research Organization; and CIMMYT, Kenya
- ***Senegal:*** Institut de Technologie Alimentaire and Institut Senegalais de Recherches Agricoles.
- ***Others:*** University of Pretoria, South Africa and A to Z Textiles, Tanzania.

[1] U.S. universities and international partners by country.

ACRONYMS

ABE	Agricultural and Biological Engineering
AC	Advisory Council
AOR	Agreement Officer Representative
CLM	Cellule de Lutte Contre la Malnutrition, Senegalese government bureau responsible for nutrition initiatives in the Senegal.
CRT	Powdered carrot
CUCK	The Cooperative University College of Kenya
CRSP	Collaborative Research Support Program
DC	Decorticated grain
DDL	Development Data Library
DIV	Development Innovation Venture
DMP	Data Management Plan
DOIs	Digital Object Identifiers
DURI	Discovery Park Undergraduate Research at Purdue
DV	Dietary value
DWB	Dry weight basis
EAR	Estimated Average Requirements
EMC/ERH	Equilibrium Moisture Content/Equilibrium Relative Humidity
FGDs	Focus Group Discussions
FPL	Innovation Lab for Food Processing and Post-harvest Handling
KALRO	Kenya at the Kenya Agricultural and Livestock Research Organization
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
INTSORMIL	International Sorghum and Millet Program
ISRA	L'Institut Sénégalais de Recherches Agricoles
ITA	Institut de Technologie Alimentaire
MAN	Mango
NCA&T	North Carolina A&T State University
OTC	Office of Technology and Commercialization
PAP	Papaya
PCT	Patent Cooperation Treaty patent
PICS	Purdue Improved Crop Storage bags
PURR	Purdue University Research Repository
RAE	Retinoic Acid Equivalent
RTE	Ready-to-eat foods
SC	Steering Committee
SSA	Sub-Saharan Africa
TPVA	Total Provitamin A Carotenoids
WG	Whole grain
WTP	Willingness-to-Pay

I) EXECUTIVE SUMMARY

The Food Processing Innovation Lab's 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. Locally available nutrient-rich value chains are also targeted for enhancing the nutrition of processed products. The activities in this report cover the period of October 1, 2015 to September 30, 2016. Progress has been made in the following key project areas: 1) development of simple moisture determination methods; 2) development of low-cost grain drying technologies; 3) testing of efficacy of hermetic storage bags such as PICS for moisture and pest control in hot and humid tropics; 4) quantitative assessment of market demand and drivers for instant food products, with and without nutritional enhancement; 5) development and/or refinement of food products and processes to drive markets in Kenya and Senegal; 6) leveraging local nutrient-rich agriculture commodities to produce nutritionally-enhanced food products and to create a sustainable market-led fortified processed grain foods; and 7) establishment of effective dissemination platforms for food technologies. The last half of the fiscal year also focused on field testing of developed technologies through workshops and trainings. These efforts also provided a framework for capacity building, scientific exchange, and strengthening/building of public private partnerships for effective technology adoption. As a main outcome, this project seeks to develop and disseminate technologies that are replicable, cost-effective, scalable, and commercially viable for smallholder farmers, food processors, and consumers in Kenya, Senegal, and other Feed the Future countries.

II) PROGRAM ACTIVITIY HIGHLIGHTS[2]

- An economic baseline survey to determine willingness to pay for post-harvest technologies. Drying on tarps to reduce grain contamination received positive feedback in the trainings in both Kenya and Senegal. Survey results showed high willingness to pay for tarps and dryers with capacity of100 kg and costing less than USD100.
- A simple, low-cost method to determine moisture content of maize before storage was developed. The method is based on the use of an affordable hygrometer (USD1.50) and EMC/ERH (equilibrium moisture content /equilibrium relative humidity) relationship for maize.
- The Hygrometer method for grain moisture testing received positive feedback in the training workshops in Kenya and Senegal. High willingness to pay for the hygrometers was observed in the Senegal.
- Baseline study of smallholder farmer grain post-harvest handling practices in Kakamega, Kenya and Velingara Senegal conducted. Analysis shows poor practices, especially in Senegal. Survey results are being incorporated in designing various interventions.
- Comprehensive design of a scalable cabinet solar dryer system consisting of cabinet and meshed drying baskets to hold the grain was fabricated at Purdue. The baskets are detachable and can used separately as a form of sanitary dryer by laying on pebble rock bed, concrete floor, or on the ground for open-air drying applications. Other accessories include cell phone charging ports on the electronics control. The system was tested on various crops including maize, fruits, and vegetables.
- Solar wrap dryer with design criteria of 100 kg/day capacity and cost of less than $100 targeting smallholder farmers was designed
- Experimental auction implemented in Senegal to test differences in trader and consumer willingness to pay for wet and dry maize 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.
- A storage study on efficacy of hermetic bags (PICS) showed that the bags serve as a barrier to moisture exchange thus significantly reducing environmental effects on stored maize
- Another study on effects of routine opening of PICS bags conducted on maize stored at various moistures (15%, 16%, 18%, and 20%) under warm tropical conditions showed that that 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.
- Gender focused studies were conducted in farming communities and households in Kenya and Senegal.to provide insight into farmers' perspectives of roles, rights, responsibilities, entitlements, and obligations for

[2] Summary of program activities for the year, no more than one page in length.

females and males. Data is being analyzed with preliminary results showing diverse and often conflicting perspectives among men and women in both countries.

- Food Processing Training and Incubation Centre (FPTIC) at the University of Eldoret was officially opened in July 2016. The Center is equipped with processing equipment for making high quality food products. The Center is being used for training women, men, and youth processors, as well as university students.
- Consumer studies in Kenya and Senegal showed high interest and WTP in instant and fortified food products. There was also high preference for whole grain food products for Kenyan consumers. The results are being used to develop appropriate food products in each country.
- 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.
- Extruder technology for producing instant flour introduced in Kenya at the FPTIC and also transferred to Touba Darou Salam Processing Unit belonging Madame Mbacke, a long-time, private partner with ITA involved in technology dissemination.

III) KEY ACCOMPLISHMENTS[3]

- Low-cost hygrometer (USD1.50) calibrated and tested in the US for grain moisture measurement and deployed to focus countries for field-testing.
- Two solar dyers designed and tested on station
    - Scalable cabinet solar dryer system consisting of fabricated and successfully tested at Purdue on various crops including maize, fruits, and vegetables
    - Solar wrap dryer for on-farm use by smallholder farmers with design criteria of 100 kg/day capacity and cost of less than $100.
- The Food Processing Training and Incubation Centre (FPTIC) for training women, men, and youth processors as well as for student was officially opened in July 2016 at the University of Eldoret.
- Extrusion technology for production of instant flour was introduced in Kenya and also transferred though Mme Mbacke, a local food processor and longtime partner to ITA, in Touba, Senegal.
- 18 graduate students have been recruited: 12 male and 6 female; 12 Ph.D. and 6 Masters. An additional 4 students are supported on research only. The students are from Kenya, Senegal, Ethiopia, Uganda, Botwana, Nigeria, South Africa, Ecuador, and USA. One student from University of Pretoria completed his PhD and is currently employed by the AFGRI Company in South Africa as a R&D Technologist.

IV) RESEARCH PROGRAM OVERVIEW AND STRUCTURE

The project has two core research components: 1) Grain drying and storage involves development and dissemination of affordable and efficient drying and storage technologies for use by smallholder farmer, and 2) Food processing and nutrition involves development of high quality, market-competitive food products, including products with improved nutrition and dissemination through incubation training centers. Building of local capacities (human and institutional) and partnerships among public and private sector are also major components of the project. Gender and environment are taken into account at all stages of the project cycle.

[3] Concise statement of achievements, linked to relevant section of annual workplan and Performance Management Plan, limited to one page in length that focuses on outputs, not process, such as Feed the Future indicators and distillation of program achievements across all program activities. Reporting on numbers of project meetings is not an output.

V) RESEARCH PROJECT REPORT[4]

a) **Objective 1: Drying & Storage - Improve moisture measurement, drying, and storage of cereals and grain legumes in the humid tropics of Africa**

Activity 1.1: Baseline Studies

i. Description: Identify drying and storage methods used by farmers and determine moisture content of grain stored by farmers in Senegal and Kenya

ii. Location: Kakamega, Kenya and Velingara, Senegal

iii. Collaborators[5]: Klein Ileleji, Charles Woloshuk, Arvind Raman, Richard Stroshine, Jess Lowenberg-DeBoer, Corinne Alexander, Jonathan Bouchet & Jake Ricker-Gilbert (Purdue, USA); Patrick Ketiem (KALRO, Kenya); Hugo DeGroote (CIMMYT, Kenya); Makhtar Samb (ITA, Senegal); Ibrahim Sarr & Katim Toure (ISRA, Senegal); Guibing Chen (NC A&T, USA); Cheryl O'Brien (San Diego State University, USA).

iv. Achievements:

a) ***Baseline surveys in Kenya***. A survey study was conducted in Kakamega County, Kenya in collaboration with local partners CIMMYT and KALRO in September 2015. The goals of the study were: i) to measure moisture and aflatoxins levels in maize during drying and storage and ii) to understand the current maize handling practices from harvest to storage. The first objective was led by the engineers and plant pathologists from Purdue University. The second objective was led by economists from CIMMYT. A representative sample of 312 households was selected. A questionnaire was used to collect basic household information and maize post-harvest operations. Topics covered in the survey included maize harvesting, transport, drying and storage technologies used. Grain samples were collected during the visits for objective 1. Data analysis and report writing were done in October 2015. Because the households were still harvesting at time of the survey, a full overview of their harvest and post-harvest activities could not be collected. A follow-up survey was conducted in December 2015 by a team of enumerators from CIMMYT in collaboration with KALRO. The objectives of the second survey were: 1) to identify the current drying and storage methods, practices, and challenges, 2) to identify the moisture testing methods used by the farmers; 3) to examine the farmers' knowledge of aflatoxin and 4) to assess the knowledge and use of hermetic storage technologies. Data were collected using a structured questionnaire, which was digitized using the CS Pro software on tablets.

Results from the first surveys showed that most farmers in the study area were small-scale subsistence farmers and maize was the main crop grown mostly for home consumption. Although the county has two rainy seasons, maize was mostly grown in the first season (March season). It took farmers about one month to carry out all maize post-harvest activities (harvesting to storage). They used open-air solar to dry maize by mostly spreading on a tarpaulin or a mat on the ground. Moisture content testing was mostly done using the local methods such as biting. Although a few farmers had heard about hermetic technologies, none of them was using them to store maize at the time of study. Analysis of responses from December survey showed that most maize was produced for home consumption, only 21% of the total production was sold. Maize production accounted for about two thirds of the household maize consumption with an average storage period of 5 months. Most of the maize was stored in woven polypropylene sacks in the main farmhouse and about half of those interviewed added pesticides.

Lessons Learned. There is need for training on best practices for maize post-harvest handling. Simple low cost drying and moisture measurement technologies will help farmers attain good quality maize. Over 70% of the maize grown in Kenya is used for household consumption, which indicates that increasing on-farm grain storage smooths consumption patterns and helps to reduce food insecurity.

[4] These should be one page per project, limited to summaries of project objectives, key activities, highlights and process toward outcomes (not scientific reports or long detailed research papers).

[5] Provide institutional affiliation and country.

b) ***Baseline survey in Senegal.*** A survey similar to the one in Kenya was conducted in Velingara, the maize growing region of Senegal. The researcher team worked with agricultural extension agents from Kolda region who were familiar with the terrain and could engaged with farming households. The goal of the survey was to understand farmers' post-harvest cultural practices and how they affect grain quality and losses. A total of 310 farming households in 9 communities were surveyed and maize samples were collected from 8 categories. These sample categories collected included ears from unharvested plants, harvested cobs that were either in a pile or stook, cobs drying outside or inside, shelled maize drying inside or outside, and maize already dried that had been kept in storage. The maize samples were processed for moisture content, kernel damage (physical and insect), ear rot diseases, and aflatoxin contamination. The survey results showed poor handling practices by farmers. Maize harvested from the field did not have aflatoxins, rather most of the aflatoxin-contaminated kernels resulted from contamination from the soil due to drying maize cobs on the bare ground.
Lessons Learned. Pre-harvest aflatoxin associated with Aspergillus ear rot disease was not an issue in the 2015 maize crop. Farmers in the Velingara region barely used any appropriate post-harvest equipment. Laying crops on the bare ground in the open air was primarily the method used for drying resulting in soil contamination. This practice appears to be the major source of the Aspergillus fungus and subsequent aflatoxin accumulation during drying and storing. Farmers need training on sanitary drying methods such as use of plastic sheets or tarpaulins to prevent grain contamination.

c) ***Experimental Auction of willingness to pay for wet vs. dry maize in Kolda and Velingara, Senegal.*** To assure no fungal growth occurs in stored maize it should be dried within 3 days of harvest to ≤ 13% moisture content. Damp weather at harvest in maize growing regions of Senegal such as Kolda and Velingara complicates maize drying. Storing damp maize increases the risk of spoilage by fungi. Several Aspergillus fungal species (primarily A. flavus) produce aflatoxins, which are potent liver toxins associated with increased cancer risk as well as negative effects on nutrition and immune systems in humans and animals. Given the importance of moisture content to safe maize storage, maize buyers and producers in the U.S. and Europe measure maize moisture content with relatively high-cost moisture meters. These meters are not readily available in most rural markets in Senegal or elsewhere in SSA. A study was conducted to determine the reliability of local methods of maize moisture determination and the value of maize moisture in a tropical savannah climate through experimental auctions conducted in Kolda; 184 traders and 236 consumers (422 participants) were randomly surveyed. Two different incentive-compatible auction mechanisms to elicit the true values of participants for six types of maize (labeled and unlabeled maize with ≤ 13, 14.0% - 15.9%, and 17.0 - 19.0% moisture content). In the auction, two practice rounds were used before eliciting maize values to help participants understand two key concepts. 1) They would bid on six types of maize, but only one type would be randomly selected for sale to avoid diminishing marginal returns on subsequent bids. 2) That their bid would be compared to all other bids that day (traders) or to a randomly determined amount (consumers) to determine if they had the 'high' offer for the randomly selected maize type. Auction results indicate that consumers and traders revealed a preference for drier maize when they knew the moisture content. However, they could not distinguish between unlabeled maize dried to ≤ 13.0 % and 14-15.9% moisture content.

d) ***Economic baseline study in Senegal.*** An economic baseline survey was conducted in May and June 2016 of 1,996 households in 210 villages to determine their willingness to pay for a drying technologies. When asked how much they are willing to pay for a solar dryer that would dry 100 kg of maize per day, the average (mean) amount was US$62.04 and the median was US$26.79. About 88% said that they would not be willing to pay over US$98. When asked if they would purchase a 10 m^2 tarp for 3000 FCFA (US$5.36) and a hygrometer for a 1000 FCFA (US$1.79), 89% said they would purchase the tarp and 87% said they would purchase the hygrometer. Willingness to pay questions are notoriously tricky because respondent can be influenced by a wide range of non-price factors (e.g. aspirations, social acceptability) and consequently lead to responses that vary substantially from subsequent purchasing, but the solar dryer responses points to a very tight budget and the importance of keeping the price of a solar dryer for on-farm

use under US$100 and the tarp/hygrometer response indicates potential willingness to invest in those items.
Lessons learned. Willingness to pay questions in the Senegal baseline survey reinforce the importance of keeping the cost of post-harvest technology for small holder farmers low.

v. Presentations and publications:
   1. Kariuki, S., DeGroote, H. and Ndegwa, M. Role of Maize Storage in Stabilizing Annual Household Maize Consumption. Presented at the African Association for Agricultural Economics (AAAE), Addis Ababa, Ethiopia, September, 2016.
   2. McCoy S., Ricker-Gilbert J., Sall M. and Bauchet J. 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.
   3. Shrestha R. Olasubulunmi M., Ileleji K., Woloshuk C., Tubbs T., DeGroote H., Shitanda D., Sarr I., and Samb M. Assessing the drying technology needs from a survey of farmers' post-harvest practices in Kenya and Senegal. I2D Exposition held by Global Engineering Program, Purdue University, West Lafayette, Indiana, April 1, 2016.

Activity 1.2: Development of Moisture Determination Methods

i. Description: Develop low cost moisture determination methods
ii. Purdue, USA, Dakar, Senegal and Kakamega, Kenya
iii. Collaborators[6]: Charles Woloshuk (lead), Klein Ileleji, Patrick Ketiem (KALRO, Kenya); Hugo DeGroote (CIMMYT, Kenya); Ibrahim Sarr (ISRA, Senegal); Guibing Chen (NC A&T, USA).
iv. Achievements:
A simple, low-cost method to determine whether maize is dry enough for storage was developed based on the use of an affordable hygrometer and EMC/ERH (equilibrium moisture content /equilibrium relative humidity) relationship for maize. The Mini Digital hygrometer, the lowest cost hygrometer of 5 types tested, was the best based on its accuracy, device-to-device variability, and ability to clearly distinguish various levels of moisture in maize. A simple illustrated information-card was developed to guide farmers on using the device and for testing its accuracy.
At NCA&T a method was developed to estimate moisture content of corn from 1000-kernel weight. The major advantages of this method: 1) Calibration is easy (triplicated measurements of the dry mass of 1000 kernels), 2) It has high accuracy at any moisture content. 3) It is robust since the dry mass does not change easily during storage. One disadvantage is that the method would probably need to be recalibrated annually and for different corn varieties and hybrids. Since the method depends on the number of corn kernels, a fast counting plate was also designed. The counting plate was tested with corn samples. The time used for counting 1000 kernels was about 15 minutes. With care, a zero error in counting the number of corn kernels can be achieved.
Lessons Learned. Initial surveys from workshop participants in Senegal and Kenya suggest that farmers will be willing to purchase and use this low cost moisture measurement approach. However, questions about the durability of the Mini Digital hygrometer, whether it would be widely adopted, and if indeed its adoption would result in a reduction in storage losses from spoilage by fungi and *aflatoxin* contamination remain to be answered.
v. Presentations and Publications:
   1. Tubbs, Tim, Klein E. Ileleji and Charles Woloshuk. A simple low-cost method of determining whether it is safe to store maize. AIMS Agriculture and Food. (In review)

[6] Provide institutional affiliation and country.

Activity 1.3: Development of grain dryers

i. Description – Develop low-cost grain drying for small holders
ii. Location: Purdue, USA, Dakar, Senegal and Kakamega, Kenya
iii. Collaborators[7]: Klein Ileleji, Charles Woloshuk, Arvind Raman, Richard Stroshine, Jess Lowenberg-DeBoer, Patrick Ketiem (KALRO, Kenya); Hugo DeGroote (CIMMYT, Kenya); Makhtar Samb (ITA, Senegal); Ibrahim Sarr & Katim Toure (ISRA, Senegal); Guibing Chen (NC A&T, USA)
iv. Achievements:
To respond to the needs of different groups of farmers and agricultural businesses, FPL is working on two solar dryer designs: 1) a cabinet solar dryer with design criteria including a 400 kg/day capacity and cost less than $500, 2) a solar wrap dryer with design criteria including a 100 kg/day capacity and cost of less than $100. Because of the investment required and capacity the cabinet dryer will probably be used mainly by farmer cooperatives or associations, grain traders or food processors. The solar wrap dryer is designed for on-farm use by small holder farmers.
    a) ***Cabinet solar dryer:*** Ileleji and his team developed and tested a multipurpose cabinet solar dryer for small and medium holder farmers. The dryer has ten 3W fans that are powered by a 12VDC deep cycle battery recharged by a 100 W photovoltaic panel. The technology consists of a drying tray, which can be used independently from the dryer. The solar dryer accommodates 9 drying trays, each of which can hold 20 pounds of wet corn in full load operation. Other features being built into the solar dryer are an electronic control console unit consisting of a charging port for cell phones and small electronic devices, Bluetooth®, and drying process control logic. Testing of the solar dryer has been going on in West Lafayette on maize, mango, carrots and tomatoes. In June/July 2016, solar dryers were shipped to Kenya and Senegal, for field testing on drying maize as well as several crops such as fruits and vegetables. One prototype cabinet dryer each were shipped to each country. The solar units were assembled and showcased at the post-harvest management workshops held in Kenya and Senegal. In Senegal, the dryer was installed at a stakeholder's business, for testing on processed food products (Figure 1).
    To further development of the cabinet dryer, Ileleji and his group of students (a graduate student in ABE, two visiting students from Columbia and Haiti, and a staff engineer) conducted several thin-layer drying experiments to simulate thin-layer drying conditions for maize in a solar dryer prototype. They determined the drying rates of three different layer thicknesses of maize (0.4 in (500 g), 0.56 in (700 g) and 0.72 in (900 g) dried at three different possible temperatures (95°F/35°C; 109°F/42°C; 130°F/54°C) that could be achieved in the dryer. Thin-layer drying tests were also conducted for rewetted maize (30% to 13%, wet basis) dried in a basket made of shade cloth mesh and one made of wire mesh to determine whether the mesh material affected the drying rate of maize. Drying rates determined were modeled using the Page equation (1949). Results showed that there were no differences between the drying rates for maize dried in a basket made of shade cloth compared to those made of wire mesh. While 500 g, the thinnest layer gave the fastest drying rate, about 3 h and 27 min, drying 900 g of maize at all the temperatures were quite close, ranging from 4h 40 min to 5h 5 min. Thin-layer drying experiments were conducted on carrots and mangoes in collaboration with the food processing and nutrition group, with the goal of utilizing the solar dryer to dry fruits and vegetables for food fortification purposes.
    Based on these results, a comprehensive design of a scalable solar dryer concept was staged and implemented at Purdue. The basic drying system consists of a meshed drying basket, which holds the crop or product to be dried, and allows upward airflow from bottom through the product. The basket can be laid on a pebble rock bed, concrete floor, or ground in the open-air for open-air solar applications and enables air contact with the product in all directions. The drying baskets prevent product contamination from foreign materials such as rocks and soil and facilitates fast handling in case of inclement weather. The dryer also has data access for downloading to the cloud using an Android device and other accessories include cell phone charging ports on the electronics control console. Research activities included the fabrication of a mini-solar thermal collector to determine collector design and performance, drying basket

[7] Provide institutional affiliation and country.

design, drying rack design, drying test bed design, and analyses of airflow patterns in the solar dryer using FLUENT Computational Fluid Dynamics (CFD) software. A test-bed prototype has been built and is currently used to test various fan configurations, drying tray configurations and airflow patterns.
Lessons Learned. Weather conditions were a primary bottleneck for testing the drying system in Indiana because they do not match the humid tropics conditions where the dryers will be used. Prototyping of the final dryer design was challenging due the difficulty in getting fabricators to complete and deliver the dyers on time.

Figure 1. Multipurpose cabinet solar dryers at Maria Distribution in Dakar, Senegal and at KALRO, Kakamega Station in Kenya

b) ***Wrap solar dryer.*** Raman, Stroshine and Lowenberg-DeBoer focused on concept for small-batch portable, solar powered grain dryer that can be sold for less than $100. After testing various dryer shapes, designs, fans, they arrived at a configuration that can dry 50 kilos of corn pre-wetted to 25-26% MC to be dried to under 13% MC in roughly 14 hours of daylight without any intentional stirring. The solar panel capacity easily allows for powering one other such system allowing to reach the goal for 100 kg of grain.
The design is innovative in that it uses a tarp (6 by 12 ft) and two plastic sheets (one transparent and one black) that wrap around the tarp on which the grain is spread. The arrangement is tucked in at the opening and exit making a divergent entry channel for the air and a convergent exit channel. Two fans powered by a 20W solar system with 6 Amp-hr battery simultaneously inflate the wrap providing easy air passage but also provide sufficient ventilation for drying the grain. The double wrap ensures that any heat from the sun is effectively trapped and raises the temperature of the drying air significantly (thus reducing its relative humidity). Two prototypes each were shipped and assembled in Kenya and Senegal for field-testing.
Lessons learned. Key observations from initial field testing are as follows:

1. The dryer works in the rain.
2. Most components for the dryer are likely to be easily sourced and cheaply even in small towns in Kenya. For example the dryer works with motorcycle batteries. During testing the regular battery was swapped with a locally purchased motorcycle battery (1000Ksh) and it worked. 20/25 Watt solar panels are widely available in local town markets, often cheaper than in the US. For example, 20 W panels were on sale for $25 25 Watt panels for $35 etc. There are plenty of tarps and plastic sheeting sellers around. Charge controllers and the fans are the only parts that would need to be sourced from outside Africa.
3. The simplicity of the dryer makes it appealing to users including ease of setting up, portability, and cost. Initial observations indicate that sensitivity of performance is affected by how the wrap is pressed over the fan and how the outlet is shaped/weighted down by stones. A suggestion was made to make the dryer foolproof by putting the fan in a base or frame around which the plastic sheeting can snugly wrap around.

4. The main area of improvement to focus on is drying performance for the 50 kg capacity dryer. Instead of the two days of drying demonstrated at Purdue the process/design should be improved to reliably dry 50 kg in one day. Two alternatives were recommended:
    i. Test dryer with high fan speed (level 2) with frequent stirring using a broom/rake.
    ii. Allow air flow from under the maize inside the dryer by having either slotted trays inside the wrap or by having a short height frame inside the dryer that supports a wire mesh on which the grain is spread.

Activity 1.4: Moisture content for safe storage and aflatoxin studies

i. Description: Determine optimum moisture for safe storage of grains and oilseeds in hermetic storage systems and assess potential for aflatoxin development in hermetic storage bags
ii. Location:
iii. Collaborators[5]: Charles Woloshuk (Purdue, USA); Hugo DeGroote (CIMMYT, Kenya); Makhtar Samb (ITA, Senegal); Ibrahim Sarr (ISRA, Senegal); Jess Lowenberg-DeBoer (Purdue, USA)
iv. Achievements:
    a) Research was conducted that compared the Purdue Improved Crop Storage (PICS) hermetic bag system with woven polypropylene bags commonly used in Sub-Saharan countries. PICS bags had the ability to prevent grain rewetting, insect colonization, and fungal spoilage under diverse environmental conditions, namely Indiana and Arkansas. The study indicated that the airtight PICS bag serves as a barrier to moisture exchange, significantly reducing environmental effects on stored maize.
    Lessons learned: Through the prevention of rewetting and insect colonization, the PICS bag was able to minimize fungal spoilage and extend the life of stored maize.

    b) Another study was conducted to determine the impact of routine opening of the storage bags for maize consumption on fungal growth and aflatoxin contamination. Maize with moisture contents (MC) high enough to support fungal growth (15%, 16%, 18% and 20%) was stored in PICS bags, which were opened weekly and exposed to humid conditions (85% RH) for 30 min over a period of 8 weeks and 24 weeks. Monitors indicated that oxygen defused into the open bags but did not reach equilibrium with the bottom layers of grain during the 30-min exposure period. Fungal colony forming units obtained from the grain surface increased 3-fold (at 15% MC) to 10,000-fold (at 20% MC) after 8 weeks. At both 8 weeks and 24 weeks, aflatoxin was detected in at least one bag at each grain moisture, suggesting that aflatoxin contamination spread from at planted source of *A. flavus*-colonized grain to non-inoculated grain.
    Lessons learned: Experimental results indicate that repeatedly breaking the hermetic seal of the PICS bags will increase fungal growth and the risk of aflatoxin contamination, especially in maize stored at high moisture content. This work also further demonstrated that maize should be properly dried prior to storage in PICS bags.

v. Presentations and Publications
    a) Timothy Tubbs, Dieudonne Baributsa, Charles Woloshuk. Impact of opening hermetic storage bags on grain quality, fungal growth and aflatoxin accumulation. Submitted to Journal of Storage Products Research. (in Review)
    b) Lane, Brett and Woloshuk, C. 2016. Assessment of hermetic storage of maize under different environmental conditions. American Phytopathological Society Annual Meeting, Tampa, FL, July 30- Aug 3.
    c) Lane, Brett and Woloshuk, C. 2016. Assessment of hermetic storage of maize under different environmental conditions. International Congress of Entomology. Orlando, FL, September 25-30. (Poster Presentation)

Activity 1.5 Gender roles in farming and in the households

i. Description: To better understand post-harvest losses with regard to perceptions of women's and men's roles in farming and household practices.
ii. Location: Kakamega, Kenya, and Velingara, Senagal
iii. Collaborators[5]: Betty Bugusu (Purdue, USA); Cheryl O'Brien (San Diego State University); Hugo DeGroote (CIMMYT, Kenya), and Moussa Sall (ISRA, Senegal)
iv. Achievements:

The gender research conducted from July 12th through August 5th of 2016 gathered data from 16 focus groups in eight villages (four per country) through focus group discussions (FGDs). The goal of the FGDs was to provide insight into farmers' perspectives of the roles, rights, responsibilities, entitlements, and obligations of females and males in these farming communities and households. Two separate focus groups by gender, male and female were conducted in each of the 4 villages. Preliminary findings are discussed below.

The decisions about harvesting, selling, and storing crops, particularly maize, is generally made by the male head of household. Women spouses are sometimes consulted regarding these decisions but ultimately husbands make the final decisions. The way income is earned and spent within a household varies from village to village and perceptions of this praxis vary depending on gender. Men tend to believe there are no disagreements about the process, regardless of the way income is generally handled in their village households. Women tend to express that disagreements do happen and reaching a solution can extend to involving village leaders including the chief.

Women who claim land ownership (i.e. that she owns the land) are extremely rare; perhaps there is a misunderstanding in communication or perhaps such women own land due to death of a husband. Whether the village follows statutory law or traditional customs, marriage or divorce, men own and inherit land as well as all the crops and profits produced from the land. Polygamy exists in all eight villages. Men and women believe the benefits of polygamy are: shared labor, extra attention to children, and extra income when children get older. The most common challenges of polygamy stated by men and women are jealousy between wives and favoritism of some wives over others. During lean times, men and women state that men are to continue bringing in income in a variety of ways. However, women similarly expressed that men do not always fulfill this role, whether by avoidance or lack of opportunity. The burden then falls on the women to find extra income from selling household items, working for richer households in exchange for food, or asking for credit from neighbors. Children tend to suffer most during lean times, followed by women and elders. Most villages have access to capital in the forms of table banking, credit or loans from banks. Women tend to have more access to loans than men, but men have more access to capital overall. Most villages also have access to food processing, but the barriers (namely lack of training, lack of time, lack of resources) are a common theme in all of the focus groups. All villages have interacted with extension agents and some farmers are extension agents themselves. Women are more likely to have access to capital or play a role in food processing than they are to work with or become extension agents. Notably, all accounts of interactions with female extension agents are positive ones. All of the participants in Kenya and Senegal would encourage youth and their own children, male or female, to become extension agents. Children's roles in the communities are similar in their daily chores. Boys' duties tend to center around animals, farming, and household repairs. Girls' duties are household chores, such as washing, cleaning, fetching water, and child care. The amount of time spent studying varies between villages and on the opinions of the men and women interviewed. Overall, boys seem to get more time for studying than girls. Both men and women in the majority of villages have leisure time and it is usually spent sleeping, praying, or in casual conversation.

Most participants in the FGDs are members of at least one farming group. The majority of such groups allow women and men, and some allow only one gender. According to Kenya's FGDs, children are generally allowed at farmer groups. In Senegal, children are generally not allowed to attend group meetings, with the exception of those who are already working on the farm. The common barriers to attending group meetings are travel time, and the common benefits are knowledge, credit, and seed. In Kenya, men and women would like more access to training, machines, farming groups, and better working conditions. Women specifically would like more responsibility in decision making and more dialogue between husbands and wives.

In Senegal, both men and women would like more access to training, machines, and fertilizer. Women specifically would like more equality in the home and responsibility overall. Men would specifically like more places for storage, more extension agents, and for their wives to not get so tired.

b) **Objective 2: Processing & Nutrition - Drive the value chain through processing to increase commercialization and improve nutrition in the humid tropics of Africa**

Activity 2.1: Food processing

i. Description: Assessment of market demand and drivers for processed and nutritionally enhanced products, and development of processes and products with potential for the marketplace.
ii. Location: Purdue, USA, Dakar and Touba, Senegal, and Eldoret and Nairobi, Kenya
iii. Collaborators[5]: Bruce Hamaker and Mario Ferruzzi (Purdue); Violet Mugalavai & Augostino Onkware (University of Eldoret, Kenya); Djibril Traore (ITA, Senegal); John Taylor and Gyebi Duodu (University of Pretoria); Hugo DeGroote (CIMMYT, Kenya).
iv. Achievements:
   a) ***Food Processing Training and Incubation Center at the University of Eldoret, Kenya.*** Work was completed on renovating an old building provided by the University of Eldoret to house the Food Processing Training and Incubation Centre (FPTIC) for training women, men, and youth processors. FPTIC is equipped with processing equipment for making flour including: destoner, decorticator, grinder/mill, and drying oven. The center was officially opened in July 2016 and is fully functional with a processing line to produce instant flours using extrusion technology (one of the project objectives for this year). The extruder was purchase in the US and shipped to Kenya in March 2016. It was installed in June 2016 by a Purdue engineering Ph.D. student (Amudhan Ponrajan), who had earlier installed a similar unit at ITA/Senegal. The FPTIC is also outfitted with tables and seats, a dust extractor, a drying cabinet (fabricated on-site by A. Ponrajan). FPL-Purdue Ph.D. student Emmanuel Ayua, (from Kenya) was involved in the installation and training of the extruder. There is still a need for packaging equipment and materials and a second drying cabinet. In addition to training and working with local entrepreneur processors, the FPTIC will be used for student training in entrepreneurship. The University is very supportive of the Center. FPTIC staff have received training in making instant cereal flours for thin and thick (ugali) porridge; they produced approximately 150 kg instant flour used for consumer preference and willingness to pay studies.
   Lessons Learned: The Food Processing Training and Incubation Centre (FPTIC) at the University has attracted the interest the University officials. This is the first time an incubation center has been established at a university (typically has been at national research centers), and this may create a new model for developing skilled entrepreneurs from the university program.

   b) ***Testing and selection of sorghum varieties for processing in Kenya.*** Different varieties of sorghum were characterized according to their tannin levels using the bleach test (see Table 1). Sorghum varieties from research and informal market with varying tannin levels i.e. no tannin, low tannin, and high tannin, were taste tested by both rural and urban respondents using a scale of 1- dislike very much to 5 -like very much. The ANOVA results of differences between means indicate that for both rural and urban respondents, low tannin and no tannin varieties scored higher means in acceptability. This means that no to low tannin are most preferred thus will be used in processing consumer products. In the case of appearance rural or urban consumers showed no preference between high and low/free tannin sorghums suggesting that the reddish color of high tannin types is not a discriminating factor in selection. The smell of low/free tannin types was preferred by the rural consumers. The selected sorghums will be used in subsequent studies including compositing with other flours (such as amaranth, cassava) and fortification with natural fortificants.

Table 1. ANOVA table of sensory characteristics of sorghum according to tannin levels.

	ANOVA	E1 High tannin Sorghum	E97 Low tannin Sorghum	MKT-RED High tannin Sorghum	SEREDO Low tannin Sorghum	T30b-1 No tannin Sorghum
Rural						
After taste	***	$3.5^{ab} \pm 0.2$	$3.0^{b} \pm 0.2$	$3.7^{a} \pm 0.2$	$3.1^{b} \pm 0.1$	$4.1^{b} \pm 0.1$
Appearance	NS	$4.1^{c} \pm 0.1$	$4.0^{bc} \pm 0.2$	$3.7^{c} \pm 0.2$	$4.0^{b} \pm 0.1$	$4.6^{a} \pm 0.1$
Flavor	NS	$2.9^{a} \pm 0.2$	$3.4^{b} \pm 0.1$	$3.7^{a} \pm 0.1$	$4.3^{b} \pm 0.1$	$4.5^{b} \pm 0.1$
Acceptability	***	$3.5^{ab} \pm 0.1$	$3.6^{ab} \pm 0.1$	$3.4^{a} \pm 0.2$	$4.1^{ab} \pm 0.1$	$4.4^{b} \pm 0.1$
Smell	***	$3.5^{ab} \pm 0.1$	$3.6^{b} \pm 0.1$	$3.6^{b} \pm 0.1$	$4.0^{ab} \pm 0. 1$	$4.5^{a} \pm 0.1$
Texture	***	$3.1^{a} \pm 0.1$	$3.6^{ab} \pm 0.1$	$3.5^{a} \pm 0.1$	$3.9^{ab} \pm 0.1$	$4.3^{b} \pm 01$
Urban						
After taste	*	$3.7^{ab} \pm 0.1$	$3.9^{b} \pm 0.1$	$3.4^{a} \pm 0.1$	$4.0^{b} \pm 0.1$	$4.0^{b} \pm 0.1$
Appearance	***	$4.4^{c} \pm 0.1$	$4.2^{bc} \pm 0.1$	$4.4^{c} \pm 0.1$	$4.0^{b} \pm 0.1$	$3.5^{a} \pm 0.1$
Flavor	***	$3.4^{a} \pm 0.1$	$3.9^{b} \pm 0.1$	$3.2^{a} \pm 0.2$	$4.1^{b} \pm 0.1$	$4.1^{b} \pm 0.1$
Acceptability	NS	$3.8^{ab} \pm 0.1$	$4.0^{b} \pm 0.1$	$3.6^{a} \pm 0.1$	$4.0^{ab} \pm 0.1$	$4.1^{b} \pm 0.1$
Smell	NS	$4.2^{ab} \pm 0.1$	$4.3^{b} \pm 0.1$	$4.4^{b} \pm 0.1$	$4.1^{ab} \pm 0.1$	$4.0^{a} \pm 0.0$
Texture	NS	$3.6^{a} \pm 0.1$	$3.9^{ab} \pm 0.1$	$3.8^{a} \pm 0.1$	$4.0^{ab} \pm 0.1$	$4.2^{b} \pm 0.1$

*** P-value < 0.001, * P-value < 0.05, NS-=not significant
Mean values with different letters significant.

Lessons learned: 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.

c) ***Consumer study on acceptance and willingness to pay (WTP) for fortified products in Eldoret***. The study was conducted by a team of partners from Eldoret, Purdue, and Pretoria Universities and CIMMYT, July 24-28, 2016. Six trained enumerators conducted the study, with 220 participants drawn from the University of Eldoret community, who were stratified into three categories; student, junior staff and senior staff. The questionnaire was electronically administered, had three main section; 1) identification section, 2) sensory evaluation of 5 products both in porridge and ugali form and 3) willingness to pay for the products. Consumers generally rated the instant products "like very much", "like", or "neither like nor dislike". Samples were prepared in both thick and thin porridges using the composite based flour base of 30% maize:70% sorghum that was determined in a pre-study by E. Ayua to be preferred by consumers. Five flour samples were used as follows: 1) traditional sifted (decorticated) maize, 2) traditional sifted (decorticated) composite, 3) instant sifted (decorticated) composite, 4) instant whole grain composite and 5) instant sifted (decorticated) composite fortificant (10% each of baobab, pumpkin seed, and carrot flours) represent a naturally fortified instant product. Results showed a trend towards preference for whole grain instant porridge and ugali (Figure 2). This is a positive finding for the project as other work under the nutrition component (Activity 2.2) show that, whole grain flours have to be used in order to practically meet the targeted 25% of recommended daily intake of iron, zinc, and pro-vitamin A when using natural fortificants only. In the WTP study, there was a clear preference for instant over the traditional flour, and further for fortified instant when information was given to the participants (Figure 3). An "in-home use" test is planned for 100 participants in late fall 2016 where subjects will be provided instant flour products to take home, prepare, and consume for up to one week, which will be followed by a WTP test.

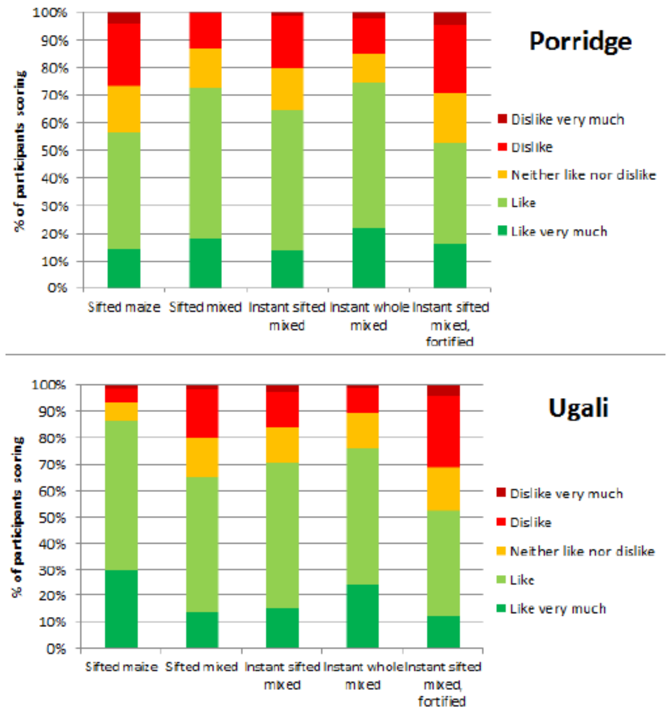

Figure 2. Results of sensory evaluation of traditional sifted (dehulled or decorticated) maize and maize/sorghum porridge (thin) and ugali (thick), extruded instant sifted and whole grain instant porridge and ugali, and maize/sorghum mix fortified sifted instant porridge and ugali.

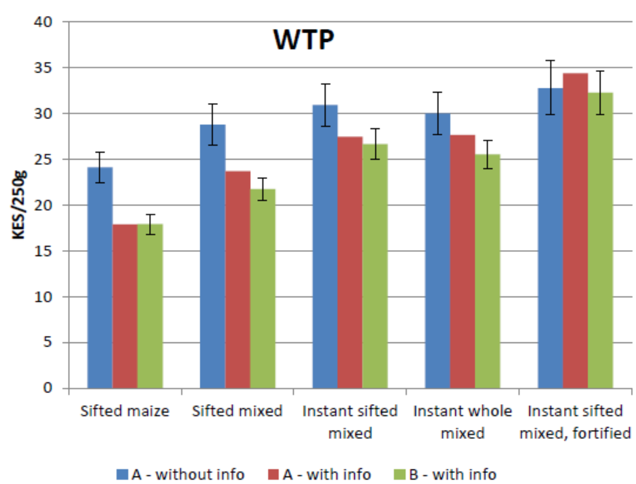

Figure 3. Willingness-to-pay for different cereal flours as described in the figure caption.

Lessons Learned: The studies showed preference towards whole grain (compared to decorticated), instant (compared to traditional), and fortified (when information about fortification was provided).

d) ***A social study on cereals and legume flours consumption in Kenya***. The study was carried out at the Eldoret Municipal market, Kenya. The goal was to determine the composite flours most preferred by consumers. Millet, sorghum, amaranth, proso millet, pumpkin seed, cassava, maize, cowpea, soybean, groundnuts, and finger millet were purchased from the cereals and legume section of the market from randomly selected sellers. The raw grains were individually cleaned, sorted and milled into flours. Groundnuts, millet, sorghum, and soybean were roasted using traditional methods and milled individually. The flour products were packaged in clear plastic containers complete with ingredients labels. Consumers had free choice to buy the flour

they desired to mix for composited flour. Consumers were also required to fill a form with their information for gender, nutritional education, if the product were for the whole family or specific family members, and any other recommendations. The sales were conducted by a woman trader at the market who had been trained on the basics of hygiene, packaging, and ingredient labeling of the products. Majority of the people who purchased the flour were women who had partial nutrition education. From the results, finger millet, sorghum, pumpkin seeds, amaranth grain and pearl millet were the most preferred cereal flours for composited flours. Cowpea flour was mainly used as a fortificant and thus was bought in smaller quantities. Cassava was also bought in small quantities and the respondents indicated that it enhanced the fineness texture of other cereals flours. The flours were mainly bought to make porridge for their households, particularly for children. A few men who bought the flour indicated that they needed it for health benefits. Most of the men chose to fortify a major cereal such as sorghum or millet with pumpkin seed flour and amaranth grain flour based on their knowledge of their nutrition benefits.
Lessons Learned: The market study showed that consumers generally had some nutritional knowledge of local foods. Buyers prefer to include millet, sorghum, pumpkin seeds, and amaranth in their composite flours. Cowpea flour is mainly used as a fortificants in smaller quantities.

e) ***Assessment of consumers' interest in instant food products in Touba Senegal***. A new low-cost extruder developed at Purdue allows small-medium enterprises to enter the market for instant processed cereal products, as well as fortified and flavored mixes. To assess consumers' interest in these products, FPL conducted a consumer study in Touba, Senegal. The study was conducted by a team of researchers from CIMMYT, Purdue University, ITA/Senegal, and the University of Pretoria. This study used a combination of affective tests and experimental auctions with 200 consumers to evaluate four new products with conventional millet four as control: instant millet flour, instant millet flour with added mango and carrot extract, and instant millet flour with added micronutrients from either synthetic or of natural origin (Figure 4). The products were coded using letters of the alphabet: A, B, C, D, and E (Figure 5). The results of the affective tests showed that consumers made little distinction between the five products in terms of appearance, aroma, taste, and overall acceptability (Figure 6). Similarly, during the experimental auctions without providing additional information on the products, there was no difference in willingness-to-pay (WTP) among them. However, after that information is provided, consumers were willing to pay a modest premium for instant flour, and a large premium for added mango and carrot extract and for added micronutrients, but not for micronutrients from natural sources. Income increases overall WTP, while education increases WTP for instant flour. The study concluded that there is a potential market for instant and fortified millet flour in Touba, but likely in the higher income and education groups.

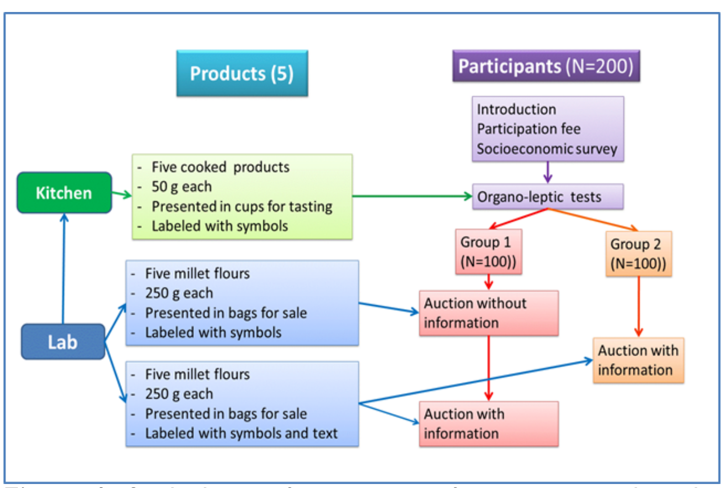

Figure 4. Study design of consumer preference test conducted in Touba, Senegal

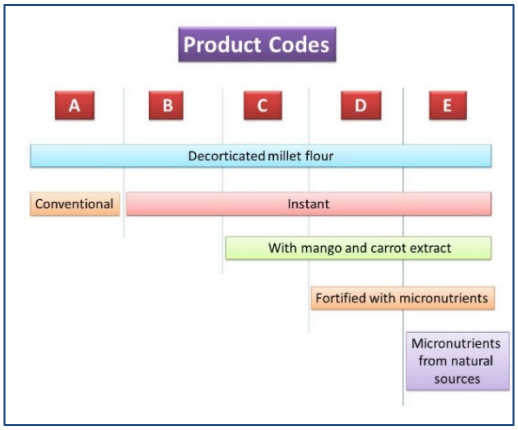

Figure 5. Product codes and the content of the different products

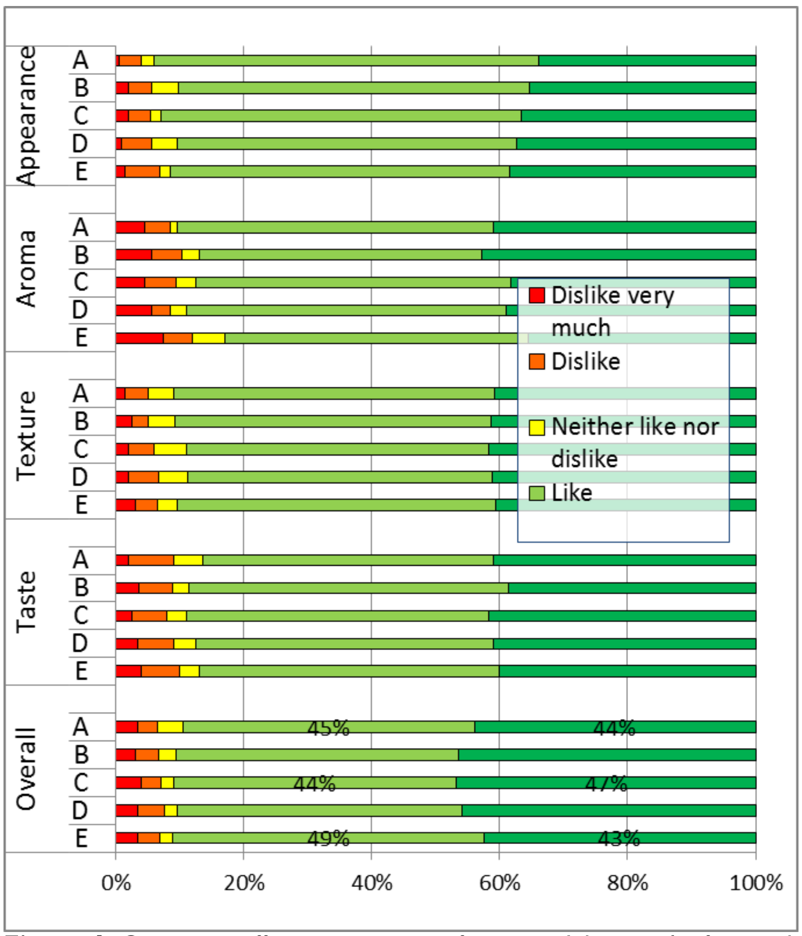

Figure 6. Consumer affective tests, on a five-point Likert scale, for attributes appearance, aroma, texture and taste, and overall appreciation.

Lessons Learned: This study showed that there is a willingness to pay for instant flour and further instant flour with nutrient fortification (synthetic and natural nutrients were the same). This study was done on a mid to lower economic group, and will be repeated in on higher level economic groups in Dakar.

f) ***FPL/ITA Entrepreneur processor partnership with Madame Astou Gaye Mbacke, owner of Touba Darou Salam Cereal Processing Unit in Touba.*** The ITA-INTSORMIL CRSP project previously identified Mme. Mbacke as an entrepreneur processor to partner with outside of Dakar in the city of Touba. Technical assistance was provided to help her start a cereal processing company, that worked to improve the livelihoods of disadvantaged women in Touba and other regions in Senegal. Mme. On March 11, 2016. ITA and FPL officially transferred the extrusion technology to her processing facility in a ceremony (~500 attendees) involving local and national leaders. Speakers included the Mayor of Touba, ITA Director General Mamadou Amadou Seck, B. Hamaker representing FPL, the Minister of Industry and Mines Ali Ngouye Ndiaye, USAID Senegal Deputy Mission Director Sharon Carter, and Mme. Astou Gaye Mbacke. Angela Records, FPL AOR from USAID Washington, also attended. This event helped increased the project's visibility with the government and other interested in processing and entrepreneurship. Mme Mbacke's facility will be used as an incubator for other women entrepreneurs, especially on the extrusion technology.

Soon after the extruder transfer at Touba, the government of Senegal expressed interest in the FPL project. The local ITA staff met with the officials from the Prime Minister's office led by his senior advisor in Agriculture, Mr. Fallou Dièye. The government has provided inouts to farmers in the region to increase millet production.

She has been receiving contracts for supply of extruded instant flour. For example a contract of 2 million FCFA was signed between officials of Sindia sponsored by the "Cellule de Lutte Contre la Malnutrition" (CLM). CLM is a government bureau directly attached to the Prime Minister and that is responsible of all nutrition initiatives in the Senegal. She succeeded in supplying the first 500 kg of instant millet flour for Sindia. The "Chambre des Métiers" (i.e., Chamber of Commerce) in the Diourbel region has also placed an order that is not yet been supplied. She has turned down some contracts due to various reasons such as low capacity of the extruder and low grain supply. She is working to contracts with farmers to buy their grain for the next season.

Lessons Learned:

With the transfer of the extrusion technology to Touba Darou Salam Processing unit, there seem to be increased demand for instant flour for adults and for weaning foods. Research is underway at ITA to develop instant weaning foods. The technology has generated an increased demand for millet thus creating a market for farmers in the community.

g) ***Collaborative product development efforts for nutrient-dense cereal-based products at University of Pretoria***.

In support of the program in Senegal:

A Masters student Mr. John Gwamba (under the supervision of Prof. Taylor and Dr. Kruger) has determined that steeping/lactic acid fermentation of whole pearl millet grain, followed by decortication (debranning) substantially improves the bioavailability of zinc and somewhat the bioavailability of iron. This is due to enzymatic degradation of phytate by lactic acid fermentation and physical removal of phytate by decortication (phytate in concentrated in the bran). Both steeping/lactic acid fermentation and decortication are commonly applied simple processing technologies widely used for small-scale grain processing in Africa.

A PhD student Mr. Isiguzoro Onyeoziri (under the supervision of Prof. Riette de Kock and Prof. John Taylor) is evaluating the shelf-life of the dry extruded pearl millet products. The objective of the study is to understand the effect of processing technologies (decortication, extrusion) on flavor profile and stability during storage. Four treatments, non-extruded whole grain pearl millet flour, non-extruded decorticated pearl millet flour, extruded whole grain millet flour, and extruded decorticated millet flour, were prepared at Purdue University and sent to Pretoria. Unfortunately, the human sensory trials planned for the reporting period had to be postponed as a result of the requirement to test the samples for pesticide residues. In anticipation of concerns related to the suitability of the USA millet grain for human consumption, the Pretoria research group has obtained local certified for human consumption pearl millet grain in Pretoria and optimized the decortication and extrusion processes using the equipment available at the University of Pretoria.

In support of the program in Kenya

A PhD student Mr. Adeyemi Adeyanju (under the supervision of Prof. Gyebi Duodu, Prof. John Taylor and Dr. Johanita Kruger) is working on development of soured sorghum, amaranth, and sorghum-amaranth composite porridges. Amaranth is a protein-rich pseudocereal, widely promoted and cultivated in East Africa. The study on protein quality shows that fermentation of sorghum using a back-slopped inoculum after cooking improves *in-vitro* protein digestibility to a greater extent than fermentation with a *Lactobacillus plantarum* starter culture or acidification with lactic acid (Table 2). Furthermore, amaranth (raw, cooked, fermented, or acidified) has higher protein digestibility than sorghum and as a result, sorghum-amaranth composites also have higher protein digestibility than sorghum alone. Including amaranth in composites with sorghum could be a useful strategy to produce fermented products with improved protein quality.

A Masters student Mr. John Lubaale (under the supervision of Prof. Gyebi Duodu and Prof. John Taylor) is studying the effect of lactic fermentation on nutritional quality and health-promoting properties of finger millet porridge.

In July 2016, Prof. Gyebi Duodu participated in the consumer study on acceptance and willingness to pay (WTP) for fortified products at the Food Processing Training and Incubation Centre of the University of Eldoret in Kenya (Figure 7).

h) ***Shelf stability of whole grain instant millet flour.*** Whole pearl millet industrialization is constrained by palatability issues and lack of processing techniques to create shelf-stable products. The objective of this work was to increase the shelf-life stability of whole grain pearl millet instant flours through extrusion. A recent study in Senegal showed that consumers are willing to pay more for instant flours and of good nutritional quality. In this study, the influence of extrusion on free fatty acids release in whole pearl millet flours over a 6-month period was evaluated. The same working study design was applied to decorticated flours, with the aim to compare the same effects on the traditional preparations. Four flours, traditionally milled and extruded, whole and decorticated, were evaluated. Samples were stored for 0, 4, 6, and 8 weeks at 4, 20, and 35C. There was a significant increase of free fatty acids in native flours, while extrusion processing stopped the increase, indicating a prevention of lipolysis.
Lessons Learned. Extrusion seems to decrease the lipolysis in whole grain millet flour resulting in higher shelf-life.

Table 2. Effect of cooking, fermentation with a *Lactobacillus plantarum* starter culture, fermentation with a back-slopped inoculum and acidification with lactic acid on % in vitro protein digestibility of sorghum, amaranth and their composite.

Treatment	Sorghum	Amaranth	Sorghum:Amaranth (70:30)
Raw	74.0 ± 0.1	89.3 ± 1.7	81.8 ± 0.1
Cooked	51.9 ± 1.8	91.3 ± 0.4	67.3 ± 0.9
Fermented*	77.3 ± 0.2	84.7 ± 0.8	82.9 ± 0.8
Fermented*/Cooked	56.4 ± 1.8	89.8 ± 0.7	74.8 ± 0.2
Cooked/Fermented*	51.9 ± 0.6	86.2 ± 1.3	63.6 ± 1.0
Fermented**	77.5 ± 0.8	81.1 ± 1.8	81.4 ± 0.3
Fermented**/Cooked	57.5 ± 0.8	87.4 ± 0.3	72.1 ± 0.1
Cooked/Fermented**	67.5 ± 0.3	85.9 ± 0.3	69.4 ± 1.3
Acidified***	76.0 ± 0.4	85.1 ± 0.8	81.1 ± 0.2
Acidified***/Cooked	53.2 ± 1.6	92.1 ± 0.5	73.5 ± 0.1
Cooked/Acidified***	46.8 ± 1.0	89.6 ± 0.8	62.2 ± 1.2

* Fermentation with *Lactobacillus plantarum* starter culture, ** Fermentation with a back slopped inoculum, *** Acidification

Figure 7. Sensory evaluation of sorghum and maize porridge products at the Food Processing Training and Incubation Centre, University of Eldoret, Kenya. A – The team; B – Preparation of samples for sensory evaluation; C – Enumerators determining willingness to buy/pay of products; D – Enumerators conducting sensory evaluation of porridge products

i) ***Effect of co-extrusion on nutrient-rich plant sources in flour.*** Work was done on mixing of nutrient-rich plant materials with millet through a co-extrusion technique to understand how the extrusion process affects product quality parameters. The results are reported in the "Nutrition" section along with the nutritional properties of the instant co-extrudates. Also, instant millet flours were made at Purdue in February to get an understanding of their sensory properties and acceptability for decision in which instant flour combinations were to be used in the Senegal consumer preference study.

j) ***Instant and micronutrient fortified food products in Senegal***. A major accomplishment of this period was processing of high quality instant millet flour and fortified products with added synthetic vitamin-mineral premix or one or both of baobab and hibiscus powders. Two students were trained to proficiency on the use of the extruder by Salif Sow (who was previously trained by Amudhan Ponrajan, Ph.D., engineering student from Purdue). Conditions were optimized to produce flour of high quality with fully gelatinized starch that were truly "instant". A simple addition of hot water to the instant flour made porridges that are comparable to those prepared traditionally by cooking). Microbial analysis conducted at ITA showed zero coliform count, which implies that extrusion kills the coliform thus making the product safe. Over 200 kg of instant decorticated millet flour was prepared at the ITA cereal processing laboratory in February for the consumer preference test that was conducted in Touba in early March and is described above under the "CIMMYT" section. Instant flours were judged by the participants of the study to be equal to or better than the traditionally prepared porridge.

v. Presentations and Publications

a) Food Processing Training Manual: developed by Prof. Violet Mugalavai and is being edited for training purposes at the FPTIC at the University of Eldoret.
b) Report on the consumer experiment in Touba: "Measuring consumers' interest in instant fortified millet products - a field experiment in Touba, Senegal" by De Groote et al. 2016 (paper submitted to the AAAE conference).

Activity 2.2: Nutritional studies

i. Description: Screening of nutrient-rich plant materials for use in consumer based food products in Senegal and Kenya.
ii. Location: Purdue, USA, Dakar and Touba, Senegal, and Eldoret and Nairobi, Kenya
iii. Collaborators[5]: Mario Ferruzzi - lead (Purdue); (Violet Mugalavai & Augostino Onkware (University of Eldoret, Kenya); Djibril Traore (ITA, Senegal); Johanita Kruger (University of Pretoria, South Africa).
iv. Achievements
   a) ***Screening of micronutrient bioaccessibility from model products***: In support of the project in both Senegal and Kenya, MSc Nutrition student Miss Reneè van der Merwe (under the supervision of Dr. Johanita Kruger and Prof. John Taylor) has determined the iron, zinc, phytate, and total phenolics contents of various locally grown plant foods as potential sources of iron and zinc for inclusion in the ready-to-eat (RTE) cereal-based food products. Analysis is on-going to estimate the bioavailability by *in-vitro* assay of the iron and zinc in these plants. The data will be used in a Decision Tree to determine the optimum composition for effective micronutrient delivery in the RTE food products.
   The major findings were that moringa had the highest iron content of 55-62 mg/100 g dry weight basis (dwb), which is 10 times higher than that in normal pearl millet, which also has the highest phenolics content that may inhibit mineral absorption. Hibiscus had the highest zinc content of 2.6-2.8 mg/100 g dwb similar to that of normal pearl millet, but also has very high in phytate content of 4200–5400 mg/100 g dwb, 4-5 times higher than pearl millet, which could substantially inhibit mineral absorption.
   Plant food blends consisting of 15% plant-based mineral source (moringa, baobab, and/or hibiscus), 5% sunflower oil, 30% provitamin A source, and 50% pearl millet, all will have phytate:iron molar ratios above 9:1 and phytate:zinc molar ratios above 30:1, well above the critical ratios where it is predicted that mineral absorption will be inhibited in a plant-based diet. A potential solution to the problem of the low levels of zinc in particular is to use iron and zinc biofortified pearl millet. Dhanashakti, a biofortified variety developed by ICRISAT in India was found to have more than double the iron content and 40% higher zinc content than regular improved pearl millet (Table 3).

Table 3. Fe and Zn contents (mg/100 g, as is basis) of high and normal Fe and Zn pearl millet.

	Fe		Zn	
CULTIVAR	**Content**	**% contribution to RDA***	**Content**	**% contribution to RDA***
Dhanashakti	9.12 ± 0.18	19.5	4.79 ± 0.14	24.0
ICMB 92111	4.43 ± 0.11	9.5	3.40 ± 0.07	17.0

Means and standard deviation (n= 2), * - Percentage contribution that 15 g of pearl millet in a 30 g solids complementary porridge with food to food fortification (50% pearl millet) could make towards the iron (7 mg/day) and zinc (3 mg/day) RDA of infants aged 12-24 months.

   M.Sc. student John Gwamba (under the supervision of Prof. John Taylor and Dr. Johanita Kruger) investigated the processing technologies of grain decortication (dehulling), steeping/lactic fermentation and parboiling singly and in combination to determine whether any could selectively remove the phytate while retaining essential minerals, with the aim of improving mineral bioavailability. None of the treatments affected phytate:iron molar ratio, which remained high (15-18:1). Phytate:zinc ratio was reduced somewhat by decortication, from 31:1 to 26:1 and somewhat further by subsequent steeping/fermentation and parboiling to 21:1. As pearl millet grain is generally decorticated (debranned) prior to milling to improve palatability, it is important that the increased iron and zinc from biofortification is not only concentrated in the bran layers of the grain. Micro-PIXE (proton induced X-ray spectrometry) was used to evaluate the distribution of the elements in the biofortified grain compared to a normal pearl millet variety (elemental distribution map for iron displayed in Figure 8.
   It was found that the iron and zinc contents in the endosperm of the biofortified grain were more than double and 60% higher, respectively compared to the normal sorghum grain (Table

4). These results indicate that the biofortification did not result in any changes in the distribution of the minerals in the pearl millet kernel. Importantly, the biofortified grain will provide appreciably higher amounts of iron and zinc to the consumer, even when consumed refined.

Table 4. Mineral concentrations (mg/kg) in the endosperm and bran layers of high iron and zinc and normal iron and zinc pearl millet.

	Endosperm		**Bran**	
	Dhanashakti	ICMB 92111	Dhanashakti	ICMB 92111
Fe	12.2 (7.2)	5.2 (0.9)	361.0 (76.5)	115.3 (37.6)
Zn	24.0 (4.9)	13.4 (2.4)	42.0 (14.9)	27.7 (5.7)

Values in parentheses are 1 standard deviation (n=3)

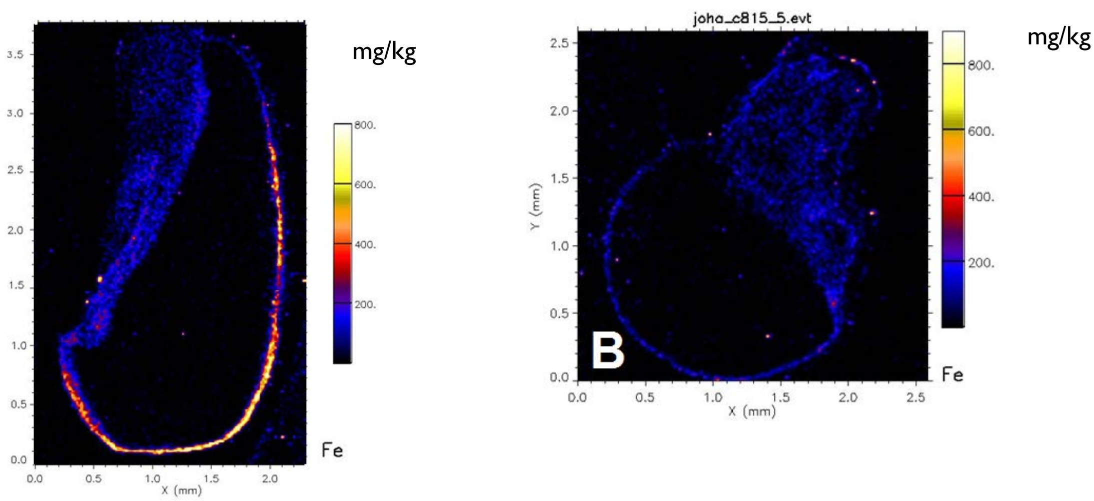

Figure 8. Quantitative iron distribution of A-*high iron and zinc* pearl millet and B-*normal iron and zinc* pearl millet.

Lessons learned: High levels of iron and zinc in the ICRISAT millet variety Dhanashakti have led the team to realize that this, or a similar, biofortified millet, if used in the whole grain form, would be an adequate starting millet material to provide the target range of micronutrients (~30% of recommended values) with further addition of locally sources nutrient-rich plant materials. FPL has been in communication with ICRISAT-Niger's Sadore Centre and the ICRISAT Mali group to explore a partnership on biofortified millet for potential use in instant fortified flours.

It was found that despite high levels of iron and/or zinc in local nutrient-rich plant sources, high phenolic or phytate content that inhibit mineral bioavailability needs to be considered and prior to recommendations for incorporation in food for fortification.

b) ***Understanding the impact of extrusion on quality attributes of instantized fruit /vegetable-cereal blends at Purdue University.*** In Senegal, interest in leveraging native plants as food ingredients for alleviating micronutrient deficiencies has grown simultaneously with the desire for new convenient forms of traditional products. Extrusion offers a cost effective path to generation of high quality instant thin and thick porridges from traditional grains. The extent to which co-extrusion of cereals and nutrient-rich plant materials can be applied to generate new micronutrient dense blended fruit/vegetable-cereal products was explored. Studies were conducted at Purdue University to understand the impact of extrusion on quality attributes of instantized fruit/vegetable-cereal blends, millet (Senegalese Souna var.) was prepared as whole grain (WG) or decorticated (DC) (ext rate=70%). Powdered carrot (CRT), papaya (PAP) and mango (MAN) were combined with WG or DC millet (25:75 %) and adjusted to ~30% moisture prior to extrusion on a Technochem Mini-Extruder© (900rpm; Final Temp = 87.9-115 °C).

Instantized products were assessed for quality attributes [color, water absorption and solubility index, pasting properties (RVA), as well as provitamin A and total carotenoids recovery (HPLC)]. Extruded products contained 6.2-74.4 and 4.4-6.9 μg/g dry weight of total and provitamin A carotenoids, respectively Figure 9 Carotenoid recovery ranged from 29.7-65.9% suggesting marginal to good stability to extrusion (Table 5). CRT blends provided highest carotenoid levels reaching 7442 ug/100g dwb due to high starting material content. Extrusion of DC millet with CRT and PAP powders had greatest impact on final color increasing browning index and chroma values respectively from 30 and 15 (DC control) to 90 and 40 (DC-CRT) and 72 and 35 (DC-PAP) ($P<0.05$). Similar effects were observed in WG products. Water solubility and absorption indexes were significantly ($P<0.05$) increased by inclusion of fruit/vegetable powders in both DC and WG products. Extrusion with fruit/vegetable powders altered physical properties of final porridges. Highest peak and final viscosities were observed in WG-CRT porridges (1517 and 2426 RVU) while MAN and PAP addition decreased viscosity. Peak and breakdown viscosities were lower in DC blends (864-1243.3 and 80.7-145 RVU) compared to DC control (2453.3 and 1978.7 RVU). These data suggest that production of extruded fruit/vegetable millet blends with reasonable recovery of provitamin A carotenoids is possible, however, the impact to physical and sensorial properties must be at the same time maintained or optimized.

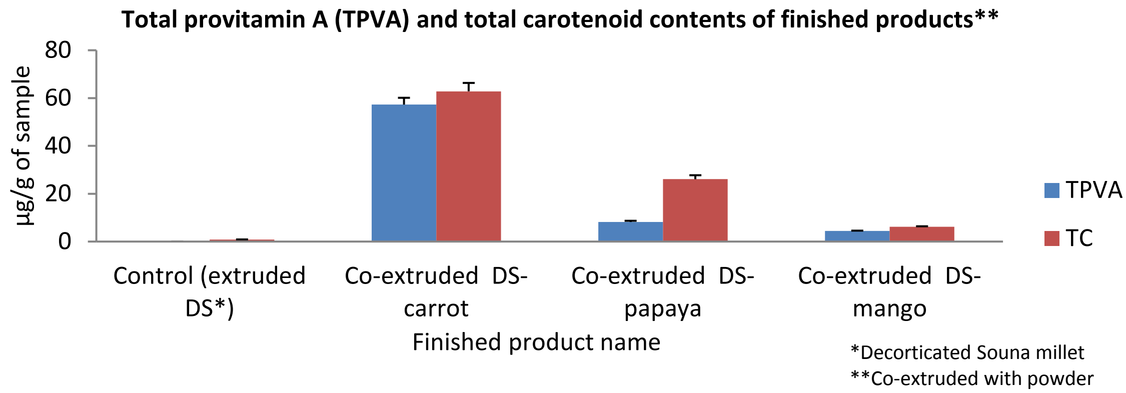

Figure 9. Total provitamin A carotenoids and total carotenoids of the final products of co-extrudates of decorticated Souna millet and dried nutrient-rich plant powders (n=3, $p<0.05$).

Table 5. Recovery of provitamin A and total carotenoids in the final co-extruded with decorticated.

	Carotenoids in ug/g* (100% DW)	**Carotenoids in ug/g* (25% DW)**	**Carotenoids in ug/g* ext.**	**Carotenoids in ug/100g* ext.**	**Recovery**
					TPVA recovery
Carrot	482.4	121	57.3	5727.00	47.5
Papaya	50.1	13	8.3	825.00	65.9
Mango	59.4	15	4.4	440.00	29.7
					TC recovery
Carrot	516.2	129	62.84	6284.00	48.7
Papaya	164.7	45.3	26.07	2607.00	57.6
Mango	65.3	17.6	6.19	619.00	35.1

* Concentration factor of 2

Lessons Learned: Co-extrusion of millet and nutrient-rich plant materials appears to be one possible path forward to making fortified instant flours, particularly since the extrusion process greatly reduces or eliminates microbial loads

c) Evaluation of Drying Methods for production of nutrient dense plant materials in Senegal and Kenya.

Leveraging of indigenous African plants for formulation of nutrient-dense blended cereal products requires the development of processing strategies that can be used to generate a nutrient dense plant ingredient. The Processing and Nutrition Component of the FPL collaborated closely with the Drying component of the overall project in assessment of drying methods for high water content plant materials in sub-Saharan countries include mangoes (Mangifera indica) and carrots (Daucus carota L.). A multipurpose solar cabinet dryer designed under FPL for grain drying was used to generate provitamin A rich powdered carrots and mangos. Drying curves were established as well as nutrient retention and color parameters of finished materials documents. Following preliminary assessments and optimization of drying curves through thin-layer drying, comparisons were made in West Lafayette, Indiana using standard drying methods including an electric dehydrator and thin layer dryer in order to understand the general performance of the solar cabinet dryer. Grated carrots (~86% moisture) were dried over 30h to finished powders (Figure 10) with moisture contents of 9.12% (Solar Dryer), 8.1% (Thin Layer Dryer) and 4.73% (Electric Food Dehydrator). Drying time and average temperatures achieved in the dryers to achieve final moisture content are shown in Table 6. The first results suggest that 8 hours were sufficient to dry the grated carrots in a Thin Layer Dryer. However, the same product would take almost 30 hours to be dried in a solar cabinet dryer. As such it is likely that a second day of repetition would be required with a solar drier to achieve similar product final moisture contents. The impact of drying method on final provitamin A carotenoid content of carrots and mangoes was assessed (Table 7).

Table 6. Drying methods used with their temperatures and drying times under 10% of moisture content of the final water content of carrot samples.

Drying method	Temperature (^{0}F)	Process drying duration (hours)
Solar dryer	92.1	27
Thin Layer	95.0	8
Electric dehydrator	95.0	4

Table 7. Total Provitamin A Carotenoids (TPVA) and Retinoic Acid Equiv (RAE) per 100g dried sample of graded carrots, sliced carrots and sliced mangos from the three drying methods used.

Grated Carrots	Raw	Solar	Dehydrated	Thin Layer
TPVA (µg/g of DM)	1196.4±20.9	863.1±17.3	852.7±19.7	881.5±15.7
RAE (µg/100g)	9927.1±18.3	7830.4±25.7	7905.2±31.5	8148.4±27.8
Recovery (%)	----	72.13	71.27	73.68

Sliced Carrots	Raw	Solar	Dehydrated	Thin Layer
TPVA (µg/g of DM)$^+$	1198.3±18.79	838.5±24.6	882.0±21.4	911.1±19.6
RAE (µg/100g)$^+$	9949.1±26.08	7566.2±27.3	7818.6±21.8	8126.3±23.8
Recovery (%)	----	69.97	73.60	76.02

Sliced Mango	Raw	Solar	Dehydrated	Thin Layer
TPVA (µg/g of DM)	42.7±0.9	15.9±0.3	24.8±0.5	34.05±1.3
RAE (µg/100g)	342.9±9.2	103.6±2.7	172.6±6.7	241.8±9.3
Recovery (%)	----	37.32	56.24	77.99

$^+$Results expressed as dry matter (DM) (n=2)

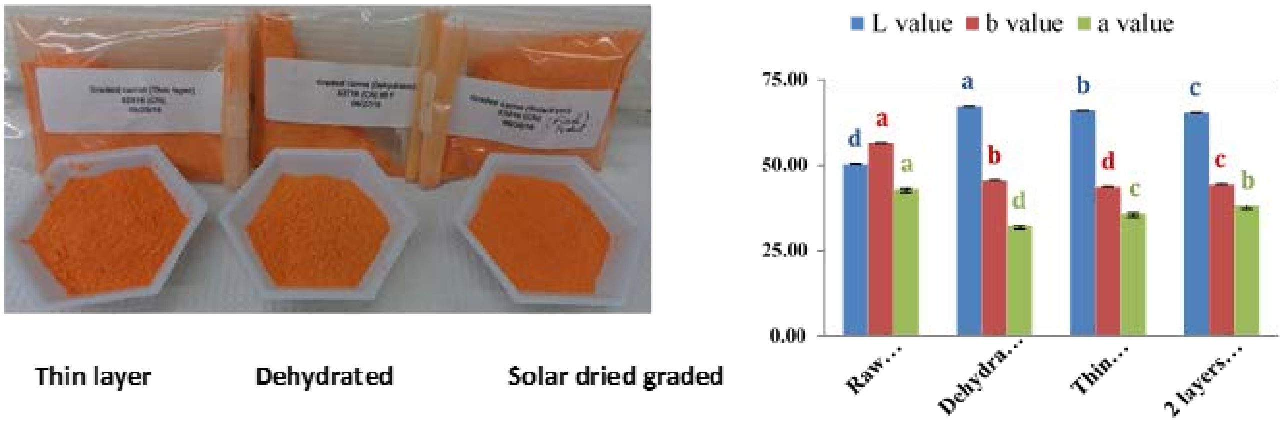

Figure 10. A. Final Carrot powders generated by different drying methods. B. Impact of drying method to final color parameters of carrot powder. Parameters (L, a, and b values) of graded carrot and finished powders was assessed using a Hunter Colorimeter.

These results suggest that while drying times may vary significantly between the Cabinet Solar and the Electric Thin Layer drying, the impact to final provitamin A content is not significantly impacted. Average recovery of total provitamin A Carotenoid (TPVA) ranged from 71-73% for grated and 70-76 for sliced carrots suggesting high recovery relative to raw carrots and more consistency for grated carrots. However, mango provitamin A recovery was observed to be more limited (~37%) from solar drying relative to Electric Thin Layer (78%). Final color was not significantly impacted by drying method with similar final color achievable by solar drying compared to electric thin layer or dehydration (Figure 10).

Thin layer drying is often used as a predictor of solar drying parameters. It was therefore expected that these two processes provide similar results. In the sliced carrot, there were similar results from the solar drying compared to thin layer; however, difference was noted in graded carrot samples. It took more time to dry the graded carrot with the solar drying compared to thin layer drying. A similar scenario was observed in the sliced mangoes, where the drying process in the solar dryer was longer than in the thin layer dryer (data not shown). Overall, these data demonstrate that solar drying may in fact be a feasible path for generation of nutrient dense carrot powders but may need additional refinement for mangoes. However these results need to be replicated in Senegal and Kenya to optimize for in country conditions. Additionally, we anticipate the leveraging of these dried materials in generation of extruded blended cereal products will be the focus of year 3 efforts with the goal to understand the impact to product quality and nutrient bioaccessibility relative to dry blended products.

Lessons Learned: Solar drying may in fact be a feasible path for generation of nutrient dense carrot powders but may need additional refinement for mangoes.

v. Presentations and Publications

1. Minnis-Ndimba, R., Kruger, J., Taylor, J.R.N., Mtshali, C. and 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.
2. Vilakati, N., Taylor, J.R.N., MacIntyre, U., and 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.
3. Ortiz D, Rocheford T, Ferruzzi MG. 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.

4. Hawi Debelo, Cheikh Ndiaye, Bruce R Hamaker and Mario G Ferruzzi. 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.
5. Darwin Ortiz, Torbert Rocheford and Mario G. Ferruzzi. Influence of temperature and humidity on the stability of carotenoids in biofortified maize genotypes. Presented at Experimental Biology 2016.

c) **Objective 3: Conduct training workshops for farmers and processors on developed technologies in Kenya and Senegal.**

Activity 1.1: Train-the-Trainer Workshop on drying and storage practices and technologies

i. Description: Conduct workshops on grain post-harvest practices in Kenya and Senegal.
ii. Location: Kakamega, Kenya and Kolda, Senegal
iii. Collaborators[8]: Klein Ileleji, Charles Woloshuk, (Purdue, USA); Patrick Ketiem (KALRO, Kenya); Hugo DeGroote (CIMMYT, Kenya); Ibrahim Sarr (ISRA, Senegal)
iv. Achievements:
Two-day Train-the-Trainer workshops on grain post-harvest practices were conducted in each country (June 23-24 in Senegal) and July 5-6 in Kenya). Participants included agricultural extension agents, service providers, and researchers: 19 in Senegal and 28 in Kenya. The research team developed 6 training materials in rack card format translated in English, French & Kiswahili. The training kicked off with a presentation on the results of the survey on maize post-harvest practices conducted the previous year in Velingara, Senegal and Kakamega, Kenya. Feedback from the workshop participants indicated that the survey results were appreciated and helpful, and gave meaning and context to the topics presented in the training afterwards. The training topics included economic importance of aflatoxin, best post-harvest practices for maize, appropriate drying practices, low-cost moisture measurement methods, and storage using Purdue Improved Crop Storage (PICS) bag technology. Approximately 600 copies of each of the 6 rack card were distributed to workshop partcipants. The highlight of the workshops was the hands-on activities on FPL developed technologies including: two moisture-measuring devices (Woloshuk's hygrometer method and Dr. Chen's kernel mass method) and Ileleji's multipurpose cabinet solar dryer. The participants were enthusiastic about the hygrometer method and voiced optimism about its usefulness.

[8] Provide institutional affiliation and country.

VI) HUMAN AND INSTITUTIONAL CAPACITY DEVELOPMENT[9]

a) Short-term training

Country of Training	Brief Purpose of Training	Who was Trained[10]	Number Trained[11] M	F	Total
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
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 University	1	1	2
USA (Purdue University)	Training in mycotoxin analysis and techniques in molecular identification of fungi	Ms. Angeline Maina, University of Nairobi, Kenya		1	1
USA (Purdue University)	Design and testing of cabinet solar dryer	Visiting undergraduate student from Universidad Nacional de Columbia and visiting graduate from Earth University, Haiti	1	1	2
USA (Purdue University)	Cabinet solar dryer design	Purdue's Discovery Park Undergraduate Research Interns (DURI).	2		2
USA (Purdue University)	Preliminary testing of the solar wrap dryer prototypes	Undergraduate students from Purdue Agricultural and Biological Engineering	1	1	2

[9] This section is to serve as a compilation of all program training activities for the 12 month reporting period and not meant to duplicate the Capacity Building section under individual Research Project Reports.
[10] Such as farmers, government officials, women entrepreneurs
[11] Disaggregate by sex if known.

b) Long –term training

i.

Name	Sex	University	Degree	Major	Program End Date[12] (month/year)	Degree Granted [13] (yes / no)	Home Country
Rose Likoko	Female	University of Eldoret	MS	Food Science	2018	No	Kenya
Harriet Nyakecho Omutimba	Female	Pwani University	PhD	Social Ethics & Gender	2016	No	Kenya
Emmanuel Ayua	Male	Purdue University	PhD	Food Science	2019	No	Kenya
Cheikh Ndiaye**	Male	Purdue University	PhD	Food Science	2018	No	Kenya
Fallou Sarr	Male	Cheikh Anta Diop University	PhD	Food Science	2019	No	Senegal
Maty Diop	Female	Cheikh Anta Diop University	PhD	Nutrition Science	2019	No	Senegal
Eliasse Diémé	Male	Cheikh Anta Diop University	PhD	Food Science & Nutrition	2019	No	Senegal
Abdourahmane Diop	Male	University of Thiès	MS	Agricultural Economics	2017	No	Senegal
Adeoluwa Adetunji	Male	Universty of Pretoria	PhD	Food Science	2015	Yes	Nigeria
Nokuthula Vilakati	Female	University of Pretoria	PhD	Food Science	2017	No	South Africa
Ayodeji Falade	Male	University of Pretoria	PhD	Food Science	2017	No	Nigeria
Isiguzoro Onyeoziri	Male	University of Pretoria	PhD	Food Science	2018	No	Nigeria
Adeyemi Adeyanju	Male	University of Pretoria	PhD	Food Science	2017	No	Nigeria
Renee van der Merwe	Female	University of Pretoria	MS	Nutrition	2017	No	South Africa
John Lubaale**	Male	University of Pretoria	MS	Food Science	2017	No	Uganda
John Gwamba**	Male	University of Pretoria	MS	Food Science	2016	No	Botswana
Tim Tubbs	Male	Purdue University	MS	Plant Science	2016	No	USA
Brett Lane	Male	Purdue University	MS	Plant Science	2016	No	USA
Stacy McCoy	Female	Purdue University	PhD	Agricultural Economics	2019	No	USA
Pablo Cesar Torres-Aguilar	Male	Purdue University	PhD	Food Science	2018	No	Ecuador
Hawi Debelo**	Female	Purdue University	PhD	Nutrition	2018	No	Ethiopia
Ravindra Shrestha	Male	Purdue University	MS	Agricultural & Biological Engineering	2017	No	Nepal

[12] Anticipated graduation date or end of program support

[13] Indicate if program support resulted in a degree

** Students were supported on research only

ii. Dr. Adeoluwa Adetunji is now employed by the AFGRI Company in South Africa as a R&D Technologist.

c) Institutional Development
   i. Description: A building was renovated by FPL to house the Food Processing Incubation Center (FPTIC) at the University of Eldoret. The building has been fitted with basic food processing equipment, a basic laboratory to test grain for processing, and an extruder for making instant flour based. The Incubation Center will be used to train food processors in Kenya and students at the university.
   ii. Partners: University of Eldoret

VII) INNOVATION TRANSFER AND SCLAING PARTERSHIPS[14]

a) Commercialization of solar drying technologies: Ileleji is exploring options to commercialize the solar drying technologies through his start-up company, JUA Technologies International LLC.
   i. Steps taken - A Patent Cooperation Treaty (PCT) patent application for the cabinet solar crop dryer filed through the Purdue University Office of Technology and Commercialization. He has been working with Purdue University Foundry, a university business incubator to develop a business and commercialization plan to make the technology available to small- and medium-holder farmers, with emphasis first in Senegal and Kenya. He is looking into applying for a USAID-DIV in collaboration with FPL and other stakeholders to pursue pilot-scale prototyping and testing in Kenya and Senegal.
   ii. Partnerships made: Ileleji visited with potential stakeholders and commercialization partners in Senegal and is also engaged with potential parts manufacturers for the solar dryer in Africa and China.
   iii. Technologies ready to scale: solar cabinet dryer is currently undergoing filed-testing in Kenya and Senegal
   iv. Technologies transferred N/A
   v. Technologies scaled N/A

b) Transfer of extrusion technology to Madame Astou Gaye Mbacke, owner of Touba Darou Salam Cereal Processing Unit in Touba. The ITA-INTSORMIL CRSP project previously identified Mme. Mbacke as an entrepreneur processor to partner with outside of Dakar in the city of Touba. Technical assistance was provided to help her start a cereal processing company, that worked to improve the livelihoods of disadvantaged women in Touba and other regions in Senegal.
   i. Steps taken - On March 11, 2016, ITA and FPL officially transferred the extrusion technology to Mme. Mbacke processing facility in a ceremony (~500 attendees) involving local and national leaders. Speakers included the Mayor of Touba, ITA Director General Mamadou Amadou Seck, B. Hamaker representing FPL, the Minister of Industry and Mines Ali Ngouye Ndiaye, USAID Senegal Deputy Mission Director Sharon Carter, and Mme. Astou Gaye Mbacke. Angela Records, FPL AOR from USAID Washington, also attended. This event helped increased the project's visibility with the government and other interested in processing and entrepreneurship.
   ii. Partnerships made: Soon after the extruder transfer at Touba, the government of Senegal expressed interest in the FPL project. The local ITA staff met with the officials from the Prime Minister's office led by his senior advisor in Agriculture, Mr. Fallou Dièye. The government has provided inputs to farmers in the region to increase millet production. Mme Mbacke has received contracts form local government official to supply instant flour. For example, a contract of 2 million FCFA was signed between officials of Sindia sponsored by the "Cellule de Lutte Contre la Malnutrition" (CLM). CLM is a government bureau directly attached to the Prime Minister and that is responsible of all nutrition initiatives in the Senegal. She succeeded in supplying the first 500 kg of instant millet flour for Sindia. The "Chambre des Métiers" (i.e., Chamber of Commerce) in the Diourbel region has also placed an order that is not yet been supplied. She has turned down some contracts due to various reasons such as low capacity of the extruder and low grain supply. She is working to contracts with farmers to buy their grain for the next season.
   iii. Technologies ready to scale: Extrusion technology with capability of producing a wide range of instant-flour based products

[14] Includes transfer of technologies and knowledge as applicable to your programs; reference the impact pathway

iv. Technologies transferred: Extrusion technology with capability of producing a wide range of instant-flour based products
v. Technologies scaled N/A

VIII) ENVIRONMENTAL MANAGEMENT AND MITIGATION PLAN (EMMP)

FPL is committed to put the mechanisms in place for environmental mitigation as outlined in the Environmental Mitigation and Monitoring Plan (EMMP). All activities conducted to date have not required environmental management strategies.

IX) OPEN DATA MANAGEMENT PLAN

The FPL Data Management Plan (DMP) was submitted to the activity manager in August 2015. A total of 9 datasets were identified for the program for eventual submission to the USAID Data Development Library (DDL), after publication or at the end of the project life cycle. In the meantime, all collected/de-identified data is stored on the Purdue University Research Repository (PURR) website managed by Purdue Libraries. PURR provides project space to manage data, and publishes datasets with Digital Object Identifiers (DOIs) and citations for Purdue PIs.

X) PROJECT MANAGEMENT ACTIVITY

The two components of the project meet on a regular basis to discuss project updates, plan future activities and resolve project–related issues as follows: 1) drying and storage – monthly and 2) processing and nutrition – biweekly. The FPL Steering/Technical Committee (SC) meets once a month to discuss the strategic direction of the project, review and approve potential funding initiatives, and resolve logistical issues. The SC also advise on the development, implementation, and monitoring & evaluation of the project, including strategic linkages and partnerships. The Advisory Council (AC) provides strategic guidance to the project and supports development of collaborative, efficient, effective science and management. The AC also helps FPL identify future trends and opportunities in post-harvest research and development. The first AC face-face meeting was held on December 12, 2014. A teleconference was also held on September 1, 2015 to provide updates on Year 1 activities and outcomes and to outline plans for Year 2.

XI) OTHER TOPICS[15]

FPL has engaged a gender expert, Dr. Cheryl O'Brien, Assistant Professor, San Diego State University (formerly from Purdue University) as a consultant to address gender issues. She works closely with the FPL PIs to ensure incorporation of gender aspects in their work. A gender-focused study was conducted in the summer of 2016 to provide insight into farmers' perspectives of roles, rights, responsibilities, entitlements, and obligations for females and males in their farming communities and households in Kenya and Senegal. Data is being analyzed

XII) ISSUES AND HOW THEY ARE BEING ADDRESSED[16]

a) The Corporative University College of Kenya, one of the collaborators on the drying and storage component of the FPL project failed to deliver on the portion of activities, even after being given several chances to do so. Purdue decided to terminate their sub-agreement. Kenya agricultural Research Organization (KALRO) will take over the activities with management oversite by CIMMYT-Kenya.
b) Dr. Corinne Alexander, a key PI to the project on impact assessment suddenly passed away in the month of January. Dr. Johnathan Bauchet, a faculty member in the Department of Consumer Sciences at Purdue joined the project to take over some of the impact assessment activities. (Biography: Jonathan Bauchet is an assistant professor in the Department of Consumer Science at Purdue University. His research interests are in international development, particularly focusing on the financial life of poor households in developing countries. He is also interested impact evaluation and its methodologies. His recent work examined the demand for life microinsurance among microfinance borrowers in Mexico, as well as the impact of an innovative anti-poverty program in Andhra Pradesh, India. He teaches courses on risk and insurance, and on

[15] Such as Regional Centers of Excellence, impact assessment, gender initiatives
[16] Such as financial, management, regulatory

consumer investment and savings decisions. Jonathan holds a PhD in Public Administration from New York University's Wagner School of Public Service, a M.A. in Sustainable International Development from Brandeis University, and a B.A. in Economics, Management and Law from Universite Pantheon Assas, Paris).

XIII) FUTURE DIRECTION

The FPL looks to be effective and relevant in the two focus countries of Kenya and Senegal through development of practical and cost-effective solutions for grain drying, storage, and food processing in the humid topics. The solutions will be beneficial to end-users including smallholder farmers, food processors and consumers in the focus countries and other Feed the Future countries. They will also be profitable for the manufacturers of the technologies, helping to create non-farm jobs. The FPL is also working to improve nutrition through food fortification strategies that are both market-driven and for use at the household level in food preparations. The strategies take advantage of the high-nutrient plant sources that are readily available but underutilized in the focus countries. FPL will help to develop these value chains for markets. The FPL is also working to identify trends and opportunities for post-harvest grain research and engagement over the next 5 to 10 years, to expand the program and keep it relevant to the stakeholder needs.

APPENDIX

A. Three distinct success stories[17]

NOTE: All reports must include the required Feed the Future branding. See page 24: http://feedthefuture.gov/sites/default/files/resource/files/Feed_the_Future_Graphic_and_Naming_Standards_Manual_june2015%281%29.pdf.

[17] Each should: a) be limited to 500 words, b) be results oriented, c) written in layman's terms, d) avoid acronyms, e) address Feed the Future priorities, and f) include a high resolution digital photo with caption and photo credit. It is okay to reference a website for more detailed information.