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

SEMI-ANNUAL REPORT

April 28, 2017

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

AACC	American Association of Cereal Chemists International
AC	Advisory Council
ASABE	American Society of Agricultural and Biological Engineers
CFD	Computational fluid dynamics
CRT	Powdered carrot
CRSP	Collaborative Research Support Program
DDL	Development Data Library
DMP	Data Management Plan
DOIs	Digital Object Identifiers
DWB	Dry weight basis
FGDs	Focus Group Discussions
FPL	Innovation Lab for Food Processing and Post-harvest Handling
KALRO	Kenya at the Kenya Agricultural and Livestock Research Organization
INTSORMIL	International Sorghum and Millet Program
ISRA	L'Institut Sénégalais de Recherches Agricoles
ITA	Institut de Technologie Alimentaire
NCA&T	North Carolina A&T State University
NIST	National Institute of Standards and Technology
OTC	Office of Technology and Commercialization
PICS	Purdue Improved Crop Storage bags
PMP	Pearl millet-based porridge
POD	Picosolar crOp Dryer
PURR	Purdue University Research Repository
RH	Relative Humidity
SC	Steering Committee
USPTO	U.S Trademark and Patent Office
WG	Whole grain
WTP	Willingness-to-Pay

I) EXECUTIVE SUMMARY

The Food Processing Innovation Lab's (FPL) goal is to increase access to safe and nutritious foods along the value chains by improving the drying and storage capacity of smallholder farmers and expanding market opportunities through diversified processed products that address market quality 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 major outcome for FPL is 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. The activities in this report cover the period of October 1, 2016 to March 31, 2017. FPL continued to make progress in all key aspects of the program including: 1) development of simple moisture determination methods; 2) development of low-cost grain drying technologies; 3) testing 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 foods; and 7) establishment of effective platforms for dissemination of food technologies. This first half of the fiscal year focused on continued field-testing and adoption of developed technologies through engagement with country extension staff, farmers, traders, and food processors. The monitoring and evaluation team was very active in administering developed technologies and assessing their potential for uptake. The engagements and monitoring and evaluation efforts provided a platform for strengthening and establishing new partnerships in the focus countries.

II) PROGRAM ACTIVITIY HIGHLIGHTS[2]

- The hygrometer was introduced to farmers, extension agents, grain traders, and others involved in FPL trials in Senegal and Kenya, where it continued to receive positive feedback as device to measure grain moisture content.
- A study to determine willingness to pay for simple, low-cost grain moisture determination devices was conducted in Kenya. Two devices were tested: the hygrometer from FPL and the Drycard (paper moisture test strip) from Hort. IL at University of California, Davis. Results from the auction show that both farmers and traders are willing to pay for the devices and suggest that there is a commercial market for these products.
- Comprehensive design of a scalable cabinet solar dryer system consisting of cabinet and meshed drying baskets to hold the grain was deployed in the field for testing. The drying system's components have been trademarked through the U.S Trademark and Patent Office (USPTO) for the following products:
  a) U.S. Trademark Serial No. 87/316,091 for "DEHYMELEON". International Class 11 for "solar powered food dehydrator"
  b) U.S. Trademark Serial No. 87/316,102 for "DEHYMELEON". International Class 07 for "solar powered electricity generators"
  c) U.S. Trademark Serial No. 87/316,107 for "DEHYTRAY". International Class 21 for "basket for dehydrating food"
- An improved design of the solar wrap dryer designated as the Picosolar crOp Dryer (POD) dryer was developed and tested in Kenya. The new design addresses problems identified in the original prototype but keeps the same design criteria of 100 kg/day capacity and costs of less than $100 targeting smallholder farmers.

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

- A storage study conducted in Senegal to determine the impact of grain moisture on aflatoxin accumulation in hermetic and woven bags showed that hermetic bags were more efficacious in preserving grain quality, by acting as a moisture barrier and preventing accumulation of aflatoxins.
- 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 females and males. Results showed a diverse and often conflicting perspectives among men and women in both countries on roles, rights, responsibilities, entitlements, and obligations. Overall, men generally made the decisions about harvesting and selling or storing of grain, particularly maize.
- The Food Processing Training and Incubation Centre (FPTIC) at the University of Eldoret was very active in research and development of new and improved food products (conventional and nutritionally enhanced); training of local food processors; and building partnerships with local private and public entities.
- 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.
- Bioaccessbility and fermentation studies have generated information for product concepts that are being used to develop nutritious food products targeting various consumer groups in Kenya and Senegal.
    - Baobab addition and various forms of fermentation have been shown to increase bioaccessibility of zinc and iron
    - Formulation of millet instant products with baobab (bouy) and moringa seems to stabilize carotenoids (provitamin A) to extrusion processing.

III) KEY ACCOMPLISHMENTS[3]

- Studies conducted on the low-cost hygrometer (USD1.50) for grain moisture measurement in Kenya, showed high Willingness To Pay (WTP) for the device by both farmers and traders.
- Two solar dyers designed and tested on station
    - Scalable cabinet solar dryer system has been trademarked
    - Picosolar crOp Dryer (POD), a redesigned version of the solar wrap dryer was deployed for on-testing in Kenya.
- The Food Processing Training and Incubation Centre (FPTIC) at the University of Eldoret was actively involved in research and development of new and improved food products (conventional and nutritionally enhanced). The Center was also engaged in training of local food processors.
- Consumer studies conducted in Kenya and Senegal have shown high acceptance and willingness to pay for instant products (with and without nutritional enhancement), setting the stage for the next step of testing the products in pilot markets with targeted consumers.
- Bioaccessbility and fermentation studies have generated information for product concepts that are being used for development of nutritious food products targeting various consumer groups in Kenya and 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, Botswana, Nigeria, South Africa, Ecuador, and USA.
    - Two students from US and Nepal completed their MS degrees at Purdue University
- Several papers have been published by various researchers on the project.

[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.

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.

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**

<u>Activity 1.1: Baseline Studies</u>

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 Bauchet & 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 – Completed and previously reported

<u>Activity 1.2: Development of Moisture Determination Methods</u>

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:

1.2.1 – Finalize analysis and write-up of study on use of the hygrometer for grain moisture determination.

The hygrometer protocol for measuring grain moisture, developed by a graduate student at Purdue, was completed and published. The hygrometer team is in talks with Global Good (http://www.intellectualventures.com/globalgood/), who have expressed an interest in designing the next generation of the hygrometer as well as other potential low-cost, grain measuring devices.

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

Lessons Learned - Feedback on the hygrometer from countries other than Kenya and Senegal indicate a potential demand by farmers/grain handlers to use the hygrometer device.

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[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.

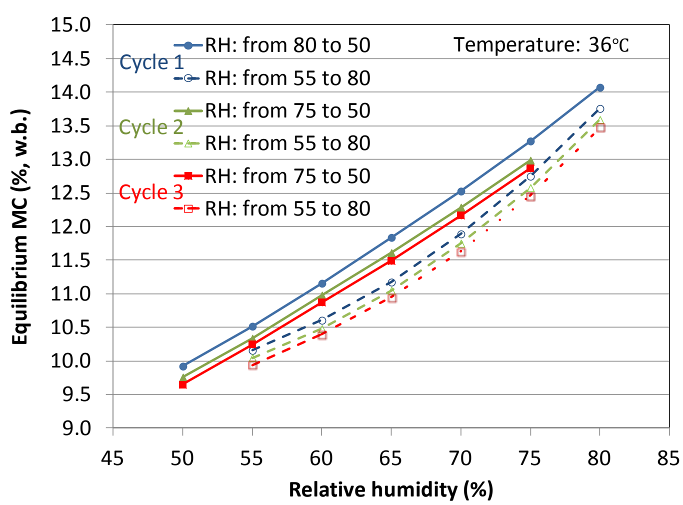
[6] Provide institutional affiliation and country.

1.2.2 – Determine the effect of wetting and drying cycles on the error in moisture determination of maize using the hygrometer method.

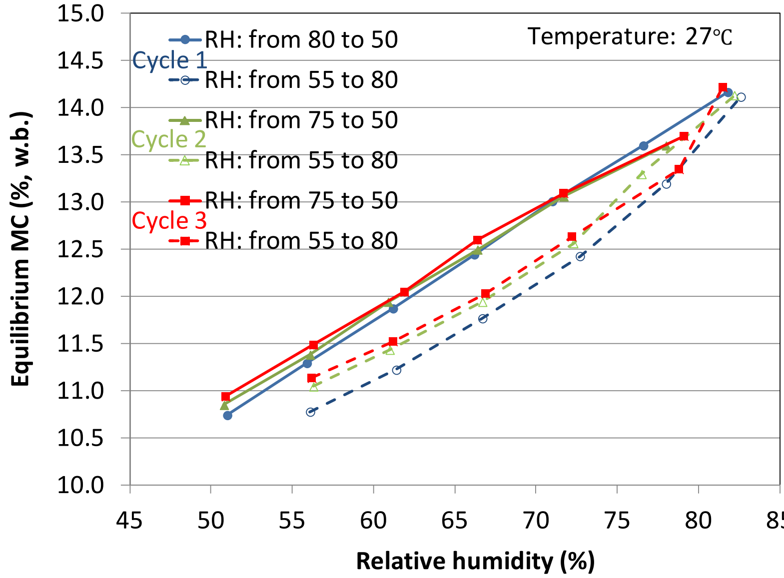
Tests were carried out by Dr. Guibing Chen, North Carolina A&T University. Yellow dent maize purchased from Detwiler Native Seed Company, Bonham, TX. Moisture content in maize was determined using the AACC method (AACC Method 44-15A; ASTM; NIST; Kenyon, A.S., Black, J.C., & Layloff, T.P. (1995); J. Assoc. Off. Anal. Chem. 78, 1109-1111). In this method, dry weight of whole maize kernels is determined by drying them at 103 °C ±1 °C for 72 hours.

The effects of drying-wetting history of grain are shown in desorption-sorption isotherms of 50g maize sample at the highest temperature (36 °C), middle temperature (27 °C), and lowest temperature (18 °C), respectively, were measured in a Caron Model 6020 environmental chamber (Caron Corporate, Marietta, OH) with controlled temperature and humidity. Under each condition (constant temperature and relative humidity), the weight of a sample was recorded after equilibration for 24 hr. At each temperature, desorption-sorption isotherms were measured three times (three cycles) using the same maize sample. Figure 1 (a), (b), and (c) shows desorption-sorption isotherms for whole maize kernel with different drying-wetting histories at 36 °C, 27 °C, and 18 °C, respectively. The desorption-sorption isotherms at each temperature formed a hysteresis loop. The same phenomenon was also observed in a previous study (Shelef, L. and Mohsenin, N.N. (1966). Moisture relations in germ, endosperm, and whole maize kernel. Cereal Chemistry, 43, 347-353). Moreover, at each temperature, same sample with a different drying-wetting history exhibited a different desorption-sorption loop. The loop progressively moved down for the second and third cycles at 36 °C, whereas an opposite trend was observed at 27 °C and 18 °C (the 3rd cycle not completed).

A specific relative humidity does not correspond to one equilibrium moisture content but a range of moisture contents at a given temperature. It seems that the maximum range of equilibrium moisture content becomes slightly narrower as temperature decreases. For maize kernels examined in this study, its value was 0.9%, 0.8%, and 0.7% at 36 °C, 27 °C, and 18 °C, respectively. For this reason, the middle value of moisture contents corresponding to each relative humidity should be used for calibrating the hygrometer method to minimize the error caused by hysteresis. In this way, the maximum error caused by hysteresis was about ±0.45% (absolute moisture content, wet basis) in the temperature range of 18°C to 36 °C.



(a)



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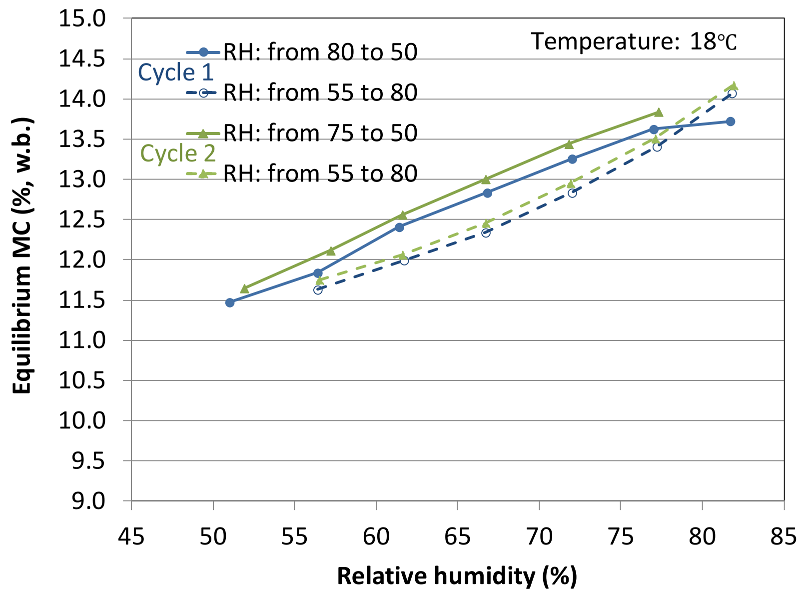

(c)

Figure 1. Desorption-sorption isotherms for whole maize kernel with different drying-wetting histories at different temperatures

<u>Activity 1.3: Development of grain dryers</u>

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:

[7] Provide institutional affiliation and country.

1.3.1 – Development of standard efficiency test for grain dryers including drying time, labor requirement, and cost of equipment.

A protocol entitled "*Multipurpose solar dryer protocol field testing guidelines*" was developed and implemented for evaluating the performance of the scalable multipurpose solar dryer, "The Multipurpose Solar Dryer" developed by Ileleji and colleagues. The portable solar dryer device is a multipurpose dryer (dehydrator) designed to provide an affordable drying technology applicable to drying several crops and processed products for small- and medium-scale farmers. The goal of the dryer design goal is to ensure that dried products meet high market standards (quality and phytosanitary) and prevent deterioration through the value chain. Field test guidelines were developed to evaluate the field performance of the multipurpose dryer for drying maize, fruits, vegetables and other crops or products of interest as suggested by collaborating partners. This guideline primarily addresses testing with maize. Another document for use with fruits and vegetables has been prepared, and a manual for the drying of fruits and vegetables was developed with the food processing group (Hamaker and Ferruzzi) in French, entitled "Sechoir solaire, importance et usage."

1.3.2 – Implement field testing of drying options on research stations and with partner organizations including farmer associations and food processors in Kenya and Senegal.

Evaluations conducted included drying rates (moisture loss over time), specific energy (kcal) per kg of water removed, thermal efficiency, drying time for moisture to reach target level from the initial level, product quality (phytosanitary, moisture content, mold and contamination level). Key drying data such as temperature, relative humidity, and airflow rates are were measured and logged during testing of the dryer. Weather data (ambient temperature, RH and solar radiation) were collected for the drying period tested. In Senegal and Kenya, weather data was collected from the HOBO weather station installed in Velingara and Kakamega, respectively. In West Lafayette, weather data from the Agronomy Farm for Research and Education (ACRE) was referenced.

(a) Multipurpose Cabinet Solar Dryer - Field drying tests were conducted for the designed multipurpose cabinet solar dryer units (solar dryer and drying tray) in comparison with the traditional method of open-air drying on a tarp as shown in Figure 2. Figure 3 shows a schematic of the solar dryer showing the sensor installations and tray configurations.

Figure 2. Comparative test of multipurpose solar dryer, drying tray in open-air, and tarp in open-air.

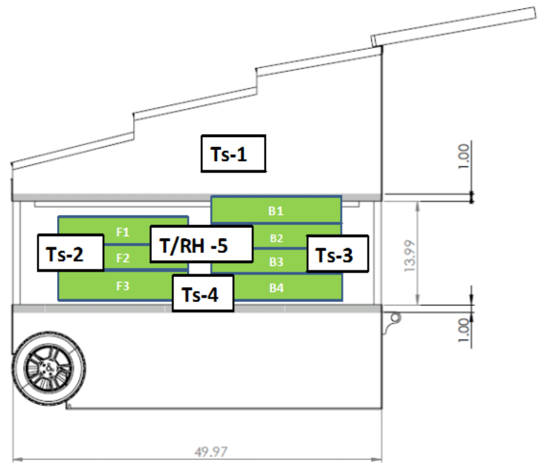

Figure 3. Schematic of solar dryer showing sensor locations.

Summary **-** The multipurpose crop dryer is applicable to drying cereal grains, oilseeds, tubers, vegetables, and cash crops like cocoa and coffee. It consists of a 1.8 m^3 drying chamber that holds 9 drying trays, each with a maximum capacity of 9 kg wet maize. However, in order to achieve a favorable drying rate, a loading rate of 5 kg wet maize per tray is suggested, thus making the solar dryer to have a total of 45 kg wet maize per batch. The design enables setting various drying modes (modes of operation) using a feedback control system to set temperature, as described under "key findings section below". For this field tests, the solar dryer was operated manually using three modes of operation based on how the thermal conditions in the dryer were changed. However, only two modes of operation could be implemented in the field tests of the fall maize harvest of 2016. The solar dryer and drying open-air in trays were tested for drying shelled maize on the field in the fall of 2016 in West Lafayette, Indiana, USA, in Velingara, Senegal and in Kakamega, Kenya with simultaneous tests conducted to compare with drying maize open-air on a tarp. The results were different for the different locations. Shelled maize dried at a faster rate in the solar dryer and drying tray compared to drying on a tarp in West Lafayette. However, all the three different drying systems compared had similar drying rates in Velingara, Senegal. In Kakamega, Kenya, the drying rates for the solar dryer and drying trays were not clearly discernible from the open-air on tarp, which may have been due to some discrepancies in how the tests were conducted. Maize in Velingara dried from 20-23% moisture content to 13% within 6-8 hours (about 10 percent points removal), which took up to 6 days in Kakamega and 2 to 3 days in West Lafayette. The faster drying rates in Velingara were due to the high temperatures and low relative humidity (RH) in Velingara compared with West Lafayette, Indiana-USA and Kakamega-Kenya. Overall, the confined drying chamber of the solar dryer presented a drying environment with better phytosanitary requirement and higher temperatures in the solar dryer chamber peaked at 5 to 7°C above the ambient depending on the location.

Key findings: Only the first mode of operation (Mode 1) and half load tests are reported. Mode 1 has only the 6 bottom fans turned on and the two fans at the back sealed. For half load tests, maize sample weighing 4.5 kg was placed in each tray and 8 trays each were placed inside the dryer and outside. To match the total sample inside the dryer, approximately 36 kg of maize was spread on the tarp in the same layer thickness as the trays. Results from each of the three sites with half load and Mode 1 operation are discussed.

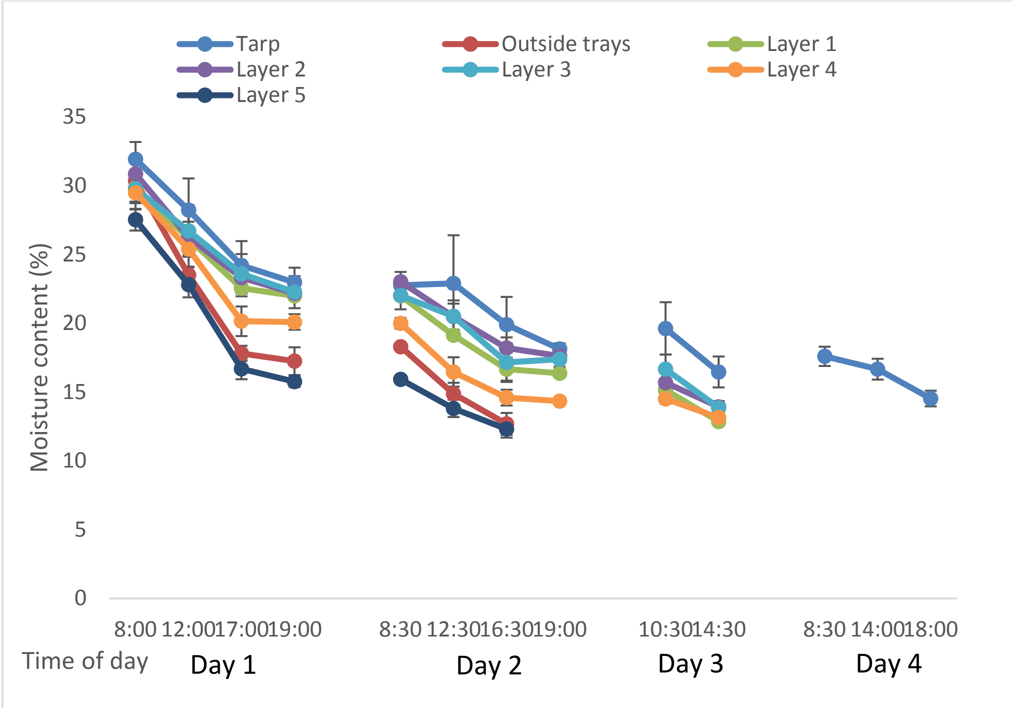

Figure 4. Variation in moisture content for half load mode 1 in West-Lafayette, USA.

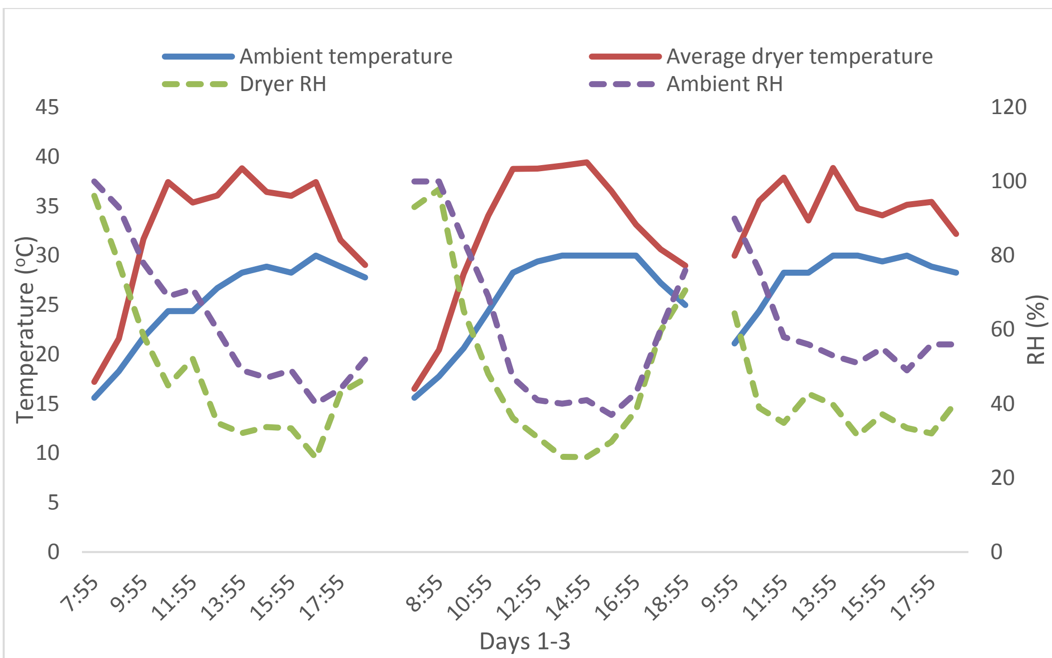

Figure 5. Variation in dryer and ambient temperature and RH for half load mode 1 in West-Lafayette, USA.

The initial moisture of the maize samples in West Lafayette ranged between 28-31%. By the middle of the second day (18 hours), layer 5 (bottom) inside the dryer and the outside trays had dried to 12-13% (Figure 4). The other layers inside the dryer needed another four hours of drying on the third day. Maize in the tarp took 4 days to complete drying. The chamber temperature peaked at 40°C, while the ambient was about 30°C. The RH of the chamber was as low at 10%, while the ambient RH was 15%.

In Kakamega, approximately 45 kg of maize was placed in the solar dryer (5 kg per tray) as well as on the tarp and 5 kg in open-air tray for half load test (only one tray used for open-air). The initial moisture of the maize was ~28%. The initial 10-point moisture drop occurred in all drying systems on the first day of drying (Figure 6). The rate of drying was negligible from Day 3-5 due to high ambient humidity in the mornings and afternoons. Also, some rewetting was observed in the samples overnight. Maize in the bottom layer inside the dryer, the open-air tray, and on the tarp dried to below 13% only slightly faster than the other dryer trays on the sixth day of drying. The peak temperatures in the solar dryer chamber ranged from 37°C to 42°C while the ambient temperature was 28°C to 30°C.

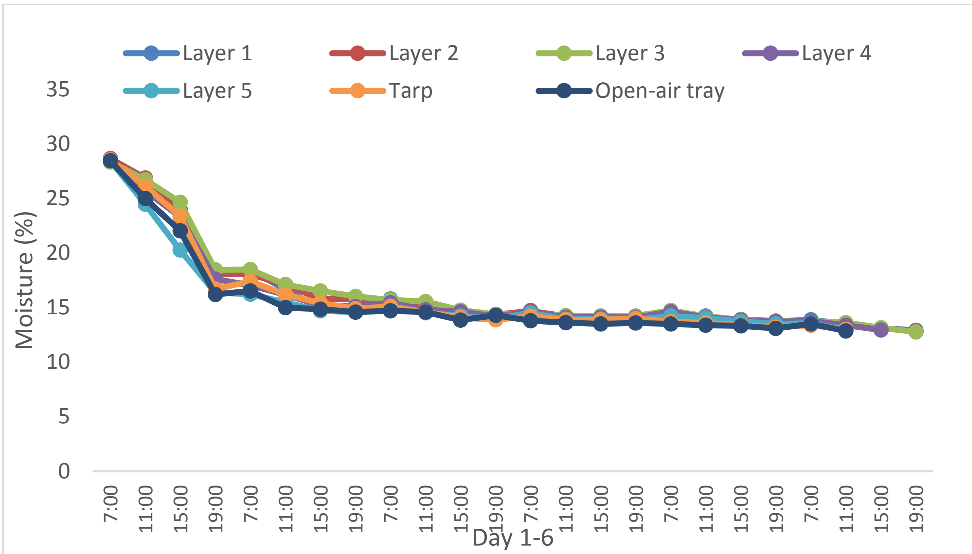

Figure 6. Variation in moisture content for half load mode 1 at Kakamega, Kenya

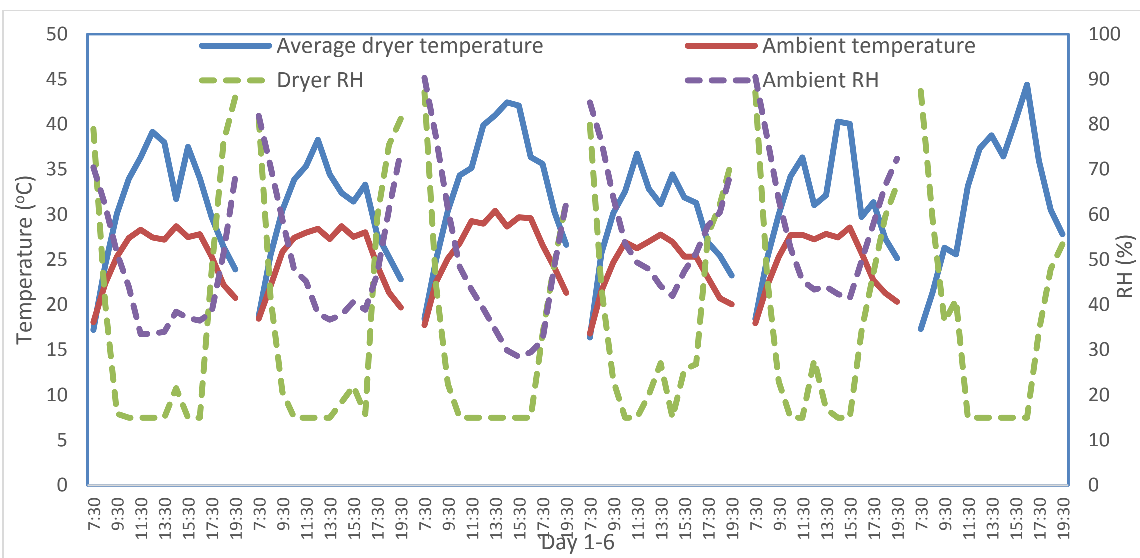

Figure 7. Variation in dryer and ambient temperature and RH for half load mode 1 at Kakamega, Kenya.

Maize drying tests with half load (i.e. ~5 kg per tray and 35 kg on tarp) were performed on three consecutive days in Velingara, Senegal. On each day, maize at initial moisture of 20-23% was dried to 13% or below within six to eight hours. As seen in Figure 8, the rate of drying was almost the same for all drying systems. High ambient temperature (>35°C) and low relative humidity can be attributed to faster and uniform drying as compared to tests in West Lafayette and Kakamega. The peak temperatures in the solar dryer chamber during the 3 days ranged from 41°C to 45°C. The temperatures and RH achieved in the solar dryer during tests conducted in West Lafayette-Indiana, USA, Kakamega, Kenya and Velingara, Senegal are shown in Figures 5, 7, and 9, respectively.

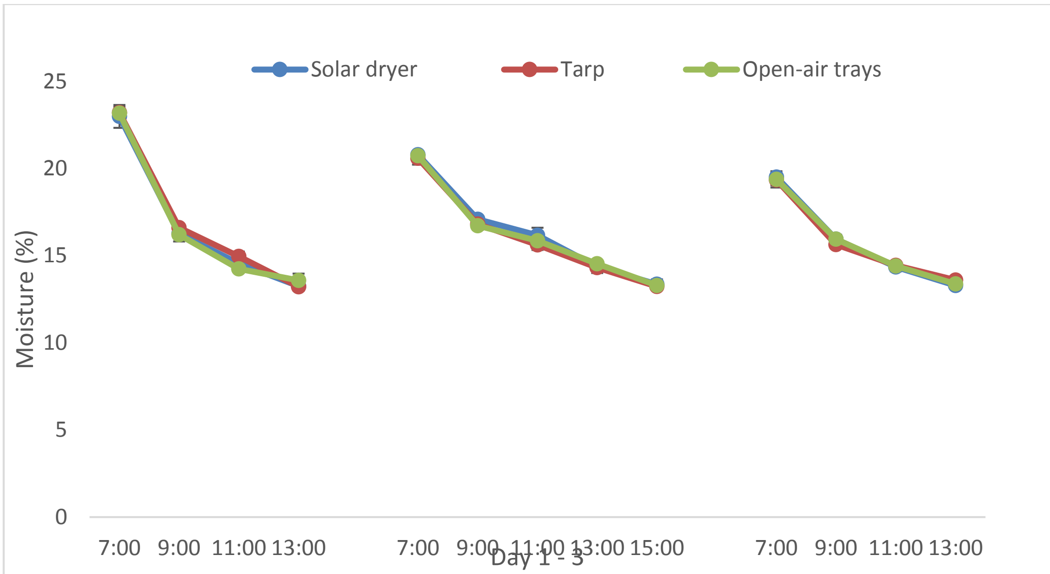

Figure 8. Variation in moisture content for half load mode 1 tests at Velingara, Senegal.

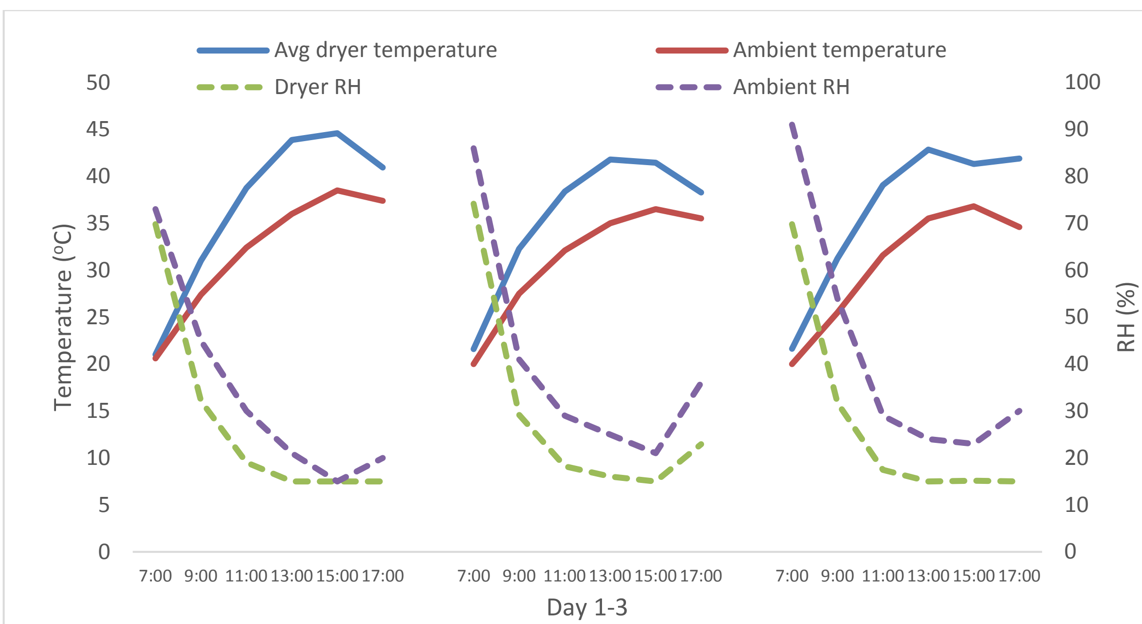

Figure 9. Variation in dryer and ambient temperature and RH for half mode 1 load tests at Velingara, Senegal.

Conclusion and Recommendations: The tests conducted in West Lafayette, IN-USA showed that the solar dryer and drying tray performed better with respect to having a faster drying rate than drying maize on a tarp. In Kakamega, Kenya the results were not discernible thus the study will be repeated. In Velingara, Senegal, all three dryings systems had the same drying rates due to the very good drying ambient conditions. Velingara had the best solar conditions for drying maize, achieving 7 to 10 percent points in 6 to 8 hours. Overall, the solar dryer with an enclosed chamber gives better phytosanitary quality. Work is on-going to improve the solar collector efficiency and to include smart control system for enhanced drying performance.

(b) Low cost on-farm solar grain dryer: Raman, Stroshine and Ketiem continued research toward development of a low cost solar dryer for on-farm use. Socio-economic research has shown a market need among African smallholder farmers for on-farm photovoltaic powered grain dryers that cost less than $100, can be disassembled and transported on the back of a motorcycle, and can dry 90 kilos of grain in one day with one hour or less of manual labor. Solar Pico Systems offer one venue for reaching the goal of drying grain within the cost constraints while using renewable energy. Solar Pico Systems are devices that can be powered by small photovoltaic panels (less than 20-30 W). They are gaining acceptance throughout Eastern Africa (e.g. M-KOPA marketed through Safaricom Ltd). These systems have traditionally been used with extremely small solar panels (< 10W) that power electrical loads such as cell-phone chargers, LED lighting, and radios. However, the 20-30W photovoltaic panels are becoming more affordable and are in the same price range as 10W panels were only a few years ago. With this capacity it becomes possible to consider powering mechanical devices with Solar Pico Systems such as small capacity grain dryers and small refrigerators.

Progress: The first version of the low cost solar dryer assembled was the Solar Wrap Dryer which consisted of a tarp on which maize was spread covered with plastic sheeting that was draped over the top of the tarp and tucked beneath the tarp. It was held in place with weights while a fan powered by a 20 W solar panel or 13 volt deep cell battery blew air into the pocket formed by the tarp and plastic. The egress of air from the dryer at the opposite end of the tarp was restricted, causing the plastic to "inflate" and form a dome over the drying maize. Tests during June through October of 2016 indicated that, although the Solar Wrap Dryer provided protection from birds, animals, and air borne contaminants, it did not dry the maize faster than laying the maize on a tarp exposed to sunlight. In fact, a side by side test indicated that a 45 kg batch of maize that could be dried to 13.5% MC in 3 days under reasonably strong sunlight required 4 days to dry to 13.8% MC using the solar wrap dryer. The dryer was tested in Kenya in October of 2016 where the sunlight was stronger, but still did not perform better than the open tarp.
The results obtained from the Solar Wrap dryer combined with discussions with colleagues at KALRO and CIMMYT in Kenya led the investigators to investigate alternate methods of drying the maize in which air would be forced through the grain instead of blowing over its surface. In open air drying scenarios, trays have been used to hold the product being dried. Therefore, a new design was developed that used wire mesh trays having a wooden frame. The new approach retained several positive features of the Solar Wrap Dryer. Those features were: 1) the covering of the maize with plastic sheets; 2) the use of a low cost fan powered by a 20 W solar panel; and 3) use of convenient and easily procurable cigarette lighter type connector between the energy source and the fan. In this approach, shown in Figure 10, the maize to be dried was placed in 5 trays that were placed side by side. Any space between the frames of adjacent trays was sealed with duct tape. The top of the trays was covered with two layers of plastic sheeting, first with a black sheet and then with a

clear sheet. Air was blown into the "pocket" formed between the tray and the sheeting so that it inflated the sheeting and formed a small chamber above the maize. The trays were slightly elevated above the ground so that air could pass through the grain and the wire mesh trays and exit the dryer underneath the each tray. Both the black plastic and clear plastic sheets were used because results from the summer and fall 2016 tests with the Solar Wrap Dryer indicated that the black sheet beneath the clear sheet helped to more effectively trap the heat from incoming solar radiation.

Figure 10. Solar POD dryer being tested by KALRO in Kakamega, Kenya, March 2017.

The new design, designated as the Picosolar crOp Dryer (POD) dryer, was first tested in early February of 2017 inside the ADM Agricultural Innovation Building, on Purdue's campus. Because there was no appreciable solar radiation available at that time, the warmth and low relative humidity of the air inside the building were used to test the performance of the new configuration. Room temperatures at the time of the test were approximately 20°C with relative humidity in the range of 16 to 18%.

In the first version of the POD dryer, the air movement was through the trays, which were elevated so that there was a gap between the bottom of the wire screen and the surface by which the tray was supported. The air traveled down the exhaust channel and exited at the end of the dryer opposite the fan. The exit was restricted, as it was in the Solar Wrap Dryer. Tests on the grain moisture from the individual trays indicated that the drying was not uniform with moistures being lower for the first and last trays and higher for the middle trays. The increased resistance to airflow in the exit pathway was believed to be responsible. As a result, the dryer was re-designed so that air exited from below the trays along both sides of the dryer, as described above.

Table 1. Moisture Contents from the Dickey John moisture meter and the Oven Method (OM*).

Date	Time	Elapsed Drying Time (hrs)	Tray 1	Tray 2	Tray 3	Tray 4	Tray 5	Average
2/2	13:45	0.0**	18.8	18.8	18.8	18.8	18.8	18.8
2/2	19:35	6.083	14.4	15.0	14.7	14.6	14.4	14.6
2/3	14:10	10.75	12.7	13.2	13.3	12.9	12.8	13.0
2/3 OM*	14:10	10.75	13.01	13.64	13.67	13.36	13.32	13.4

*OM means 72 hour, 103°C, whole kernel oven test according the ASABE Standard S352

** Initial MC using OM was 18.86%

The test on the POD dryer was conducted over a period of two days using shelled maize that had been re-wetted to 18.9% MC. On the first day the maize was dried for 6.08 hours and on the second it was dried for an additional 4.67 hours. Moisture content measurements on maize samples from the individual trays are shown in Table 1. Approximately 4 percentage points of moisture were removed on the first day and an additional 2.2 points on the second day. When drying began and also at the end of the first drying day (5 hours of drying), the relative humidity in the building was about 16%.

An indoor/outdoor thermometer was used to measure the ambient air temperature and the temperature of the air exiting the dryer trays. The exhaust air temperature was about 2°C below ambient when drying was first started and also after 5.75 hours of drying, when the shelled maize was at about 14.6% mc. This indicates evaporative cooling was taking place as the air was picking up moisture from the shelled maize. The exhaust air temperature was only about 0.6°C below ambient at the end of drying on the second day (10.75 hours of drying) when the moisture of the shelled maize was about 13.0%. Therefore, there was still some drying being accomplished because there was some evaporative cooling. However, it was much less than on the previous day because the shelled maize was much dryer.

The relative humidity of the air entering the dryer and the air exiting the dryer at tray 4 were measured during the drying process using a Psychrodyne Instrument, which determines both the wet bulb and dry bulb temperatures of the air. After 5 hours of drying the exhaust air relative humidity was 21% indicating the air was picking up moisture from the maize. However, much of its water carrying capacity was not being used. Note that, at this time, the maize was about 15.0% MC, which is relatively dry but still not sufficiently dry for storage in the hot African weather conditions.

The moisture contents of the maize in the different trays were relatively uniform during drying. At the end of the first day they varied from 14.4 to 15.0 percent, as determined with the GAC 2100 moisture meter. This is a spread of only 0.6 percentage points. The final moisture contents of the trays varied from 12.7% to 13.3% (range of 0.6 percentage points) based on GAC 2100 measurements. According to oven moisture measurements on samples taken at the same time, the moisture of the maize on the trays varied from 13.01% to 13.67% (0.66 percentage points). These results indicate that the goal of achieving relatively uniform drying of the maize was achieved.

After the initial testing was completed at Purdue, the POD dryer with written directions on the assembly and operation of the dryer were sent to KALRO in Kakamega, Kenya where tests were conducted by Mr. Patrick Ketiem. Raman and Stroshine also connected with Ketiem via a Skype session to explain proper assembling and operation of the dryer as seen in pictures in Figures 11 and 12. The dryer was placed next to an open tarp and performance monitored concurrently (Figure 10, right). Figure 12 shows a moisture meter sample being acquired.

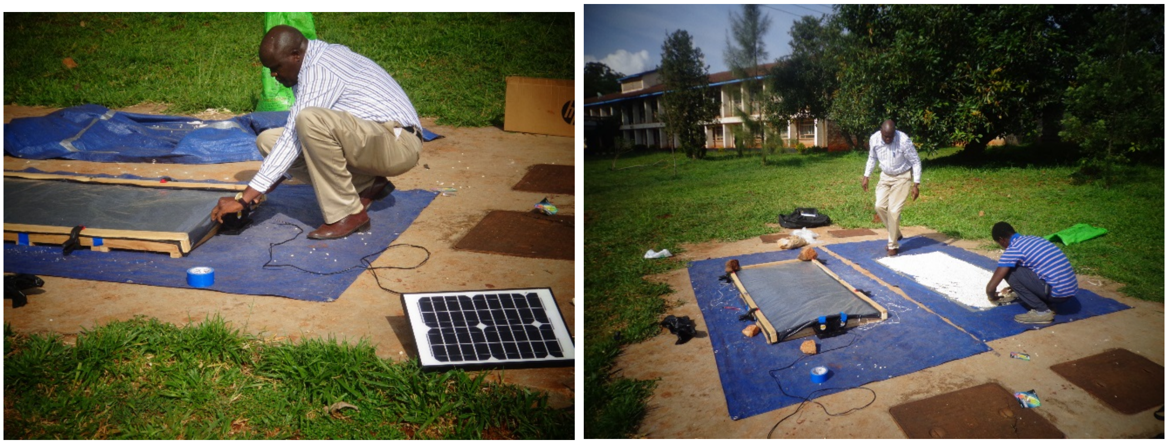

Figure 11. Preparation for the drying test comparing performance of the POD dryer with that of an open tarp. Tests were conducted by Mr. Patrick Ketiem and his assistance at KALRO in Kenya

Figure 12. Patrick Ketiem and assistant monitoring moisture content during a drying test at KALRO in Kenya.

Results: Figure 4 shows that moisture measurements made on maize from the tarp and on maize from each of the trays during his latest drying test. Moisture content is plotted versus drying time. The shelled maize dried on the tarp was initially several percentage points wetter than the maize dried with the POD dryer. However, the lines have similar slopes, indicating that the drying rates for the two dryers were about the same. In addition, the POD dryer dried maize to 13.5% moisture whereas the tarp was not in the same timeframe. The Solar POD dryer heated the air approximately 5°C above ambient temperature thereby lowering its relative humidity to the point where it could continue to dry the grain even when the ambient air humidity increased. One concern reported was that the drying was slower for the maize in the middle Tray 3. Ketiem proposed that this was caused by uneven distribution of the solar heat within the POD dryer compartment.

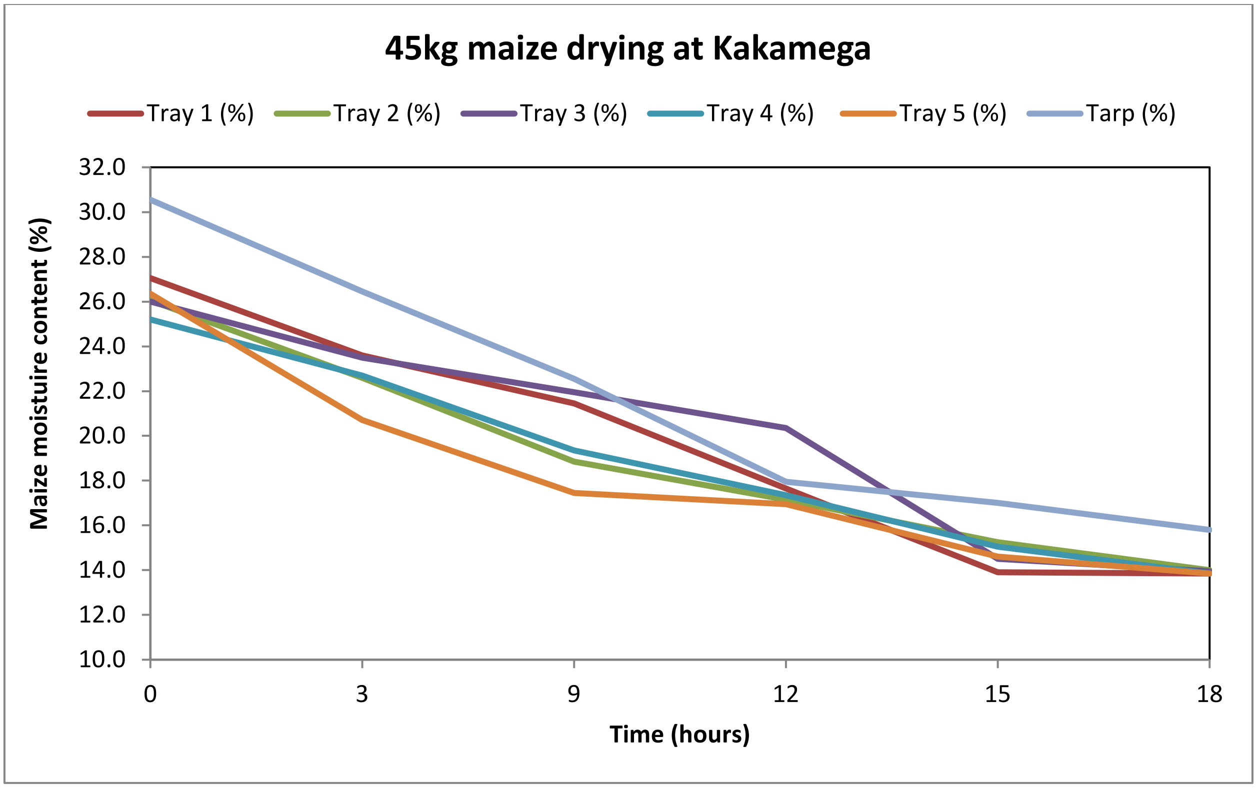

Figure 13. Summary of moisture measurements of maize drying on a tarp and of maize from each of the five trays of the POD dryer during an 18 hour drying test using a 45 kg batch of maize.

Raman and Stroshine are in the process of reviewing these data to gain more insight into the performance of the dryer so they can devise additional tests to be conducted with the goal of improving the performance of the dryer while also addressing several recommendations in Ketiem in his report. They will also prepare for additional tests of the dryer at KALRO in August 2017, including on-farm demonstrations of the POD dryer. They have also met with Purdue's Office of Technology Commercialization (OTC) to discuss IP for the POD dryer. OTC is reviewing the disclosure to determine whether the technology can be patented. The tests that will be conducted in Africa and at Purdue during the next 10 months should optimize the design so that rapid drying is achieved while the cost of building the POD is kept low.

1.3.3 – Implement field testing of solar drying options on-farm in Kenya and Senegal
Informal feedback is being elicited from farmers who visited the research station during dryer testing in Kenya and Senegal. In Kenya a structured questionnaire is being developed to use at the Kakamega Agriculture Show in June 2016 and other occasions in which the solar dryers are demonstrated. Contacts are being developed with farmer groups for on-farm testing in years 4 and 5 of FPL.

1.3.4 – Complete modeling efforts for solar cabinet dryer and validate with field data.
The multipurpose solar dryer and drying trays (Figure 14) was designed to accommodate the drying of several types of crops and processed products namely: grains and cereals (maize, sorghum, rice, soybean, etc.), fruits (mangoes, bananas, peaches, etc.), vegetables (leafy greens, peppers, tomatoes, herbs, etc.), tubers (sweet potatoes, cassava, yams, etc.), cash crops (coffee, cocoa, etc.) and processed granular products (couscous, shakri, araw, etc.).

During the design and prototyping phase, Computational fluid dynamics (CFD) simulation was used to determine the number and location of fans that pull heat from the collectors (8 fans), or the 2 fans at the back that cool the chamber by pulling air from the ambient (Figure 15).

Figure 14. The multipurpose solar dryer, left to right: engineering rendering (left), assembled unit (center) and drying tray (right).

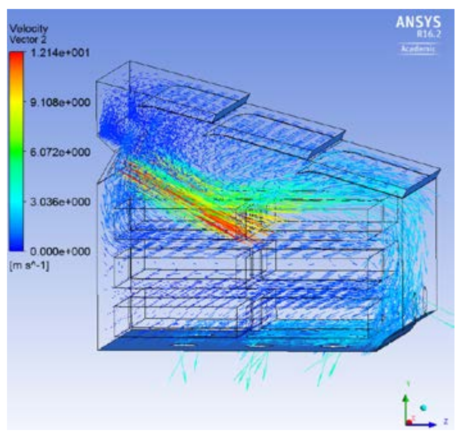

Figure 15. Airflow simulation in solar dryer prototype that was done during prototyping using ANSYS-FLUENT CFD Analysis.

1.3.5 – Complete design of biomass field drying stove, fabricate prototypes, test stove options at Purdue and deploy to Senegal and Kenya for testing – Biomass drying stove research is on hold until work on the solar cabinet dryer completed.

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:

Activity 1.4.1 – Complete study examining the environmental impacts on grain stored in hermetic bags and woven bags on grain quality and fungal populations.

Woloshuk and students completed an experiment that compared hermetic storage bags (PICS) with woven bags under two environmental conditions. The 3-month storage experiment was replicated in West Lafayette, IN and Marianna, AR. The goal was to assess the potential of grain rewetting and its effect on aflatoxin accumulation. The study also examined the fungal microbiome on the stored grain. The microbiome is a profile of the fungi on the grain obtain by the analysis of DNA sequences (specifically the ITS2 region of rDNA). A total of 833,673 and 595,232 DNA sequences were analyzed from the ground and kernel wash reads respectively, with a total of 135 genera identified. Results indicate that the genera identified by traditional plating methods (*Gibberella, Aspergillus, Penicillium,* and *Alternaria*) were among the dominant genera identified in the sequenced data. The results also indicate few differences between location and bag types, suggesting that the microbial biome and fungal diversity of stored maize was fixed in the initial grain.

Publication: Lane, B. and Woloshuk, C. P. Impact of storage environment on the efficacy of hermetic storage bags. Journal of Stored Products Research. (in Press).

Lessons Learned: If grain is stored dry (<14% Moisture Content) *Aspergillus flavus* does not grown and aflatoxins do not accumulate, regardless of the storage bag type. Our microbiome study suggested that the microbial biome and fungal diversity of stored maize may be fixed based on the region the crop was grown and stored.

<u>Activity 1.5 - Assess potential for aflatoxin development in hermetic bags</u>

i. Description: To better understand aflatoxin development in hermetic bags in the US, Kenya and Senegal.
ii. Location: West Lafayette, IN, USA; Kakamega, Kenya; and Velingara, Senegal
iii. Collaborators[5]:
iv. Achievements:

1.5.4 – Determine impact of grain moisture on aflatoxin accumulation in hermetic bags in Senegal and Kenya – Trials are in progress in Senegal and Kenya.
In Senegal maize was stored in hermetic and woven bags at 18% and 13% moisture content. For the maize stored at 18% after one month, the moisture content dropped only by 2% in hermetic bag and 6% in woven bags reaching 16% and 12% respectively. At the same time, the aflatoxin accumulated in both bags but much more in woven bags (Figure16).

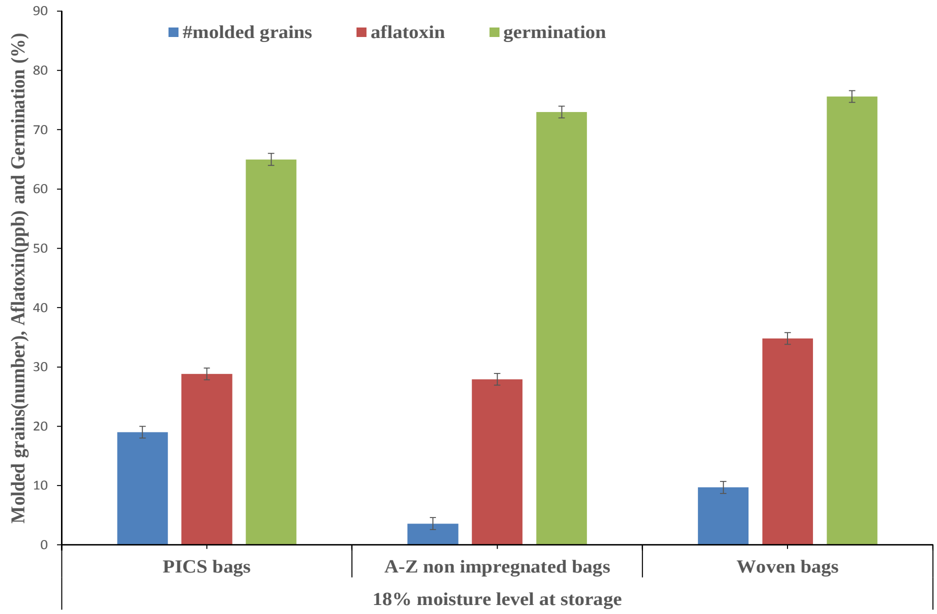

Figure 16. Contamination and quality of maize at 18% moisture content after one month storage in hermetic bags in Velingara, Senegal

In the trial in Senegal maize stored at 13% showed a moisture content drop that was slower and smaller with 1% in the hermetic bags and 2% in woven bags. The hermetic bags showed more efficacy in preserving the grain quality, particular with impregnated A-Z bags where no insects were found. Additionally, aflatoxin accumulated more in woven bag but no significant difference was noted in both bags (Figure17).

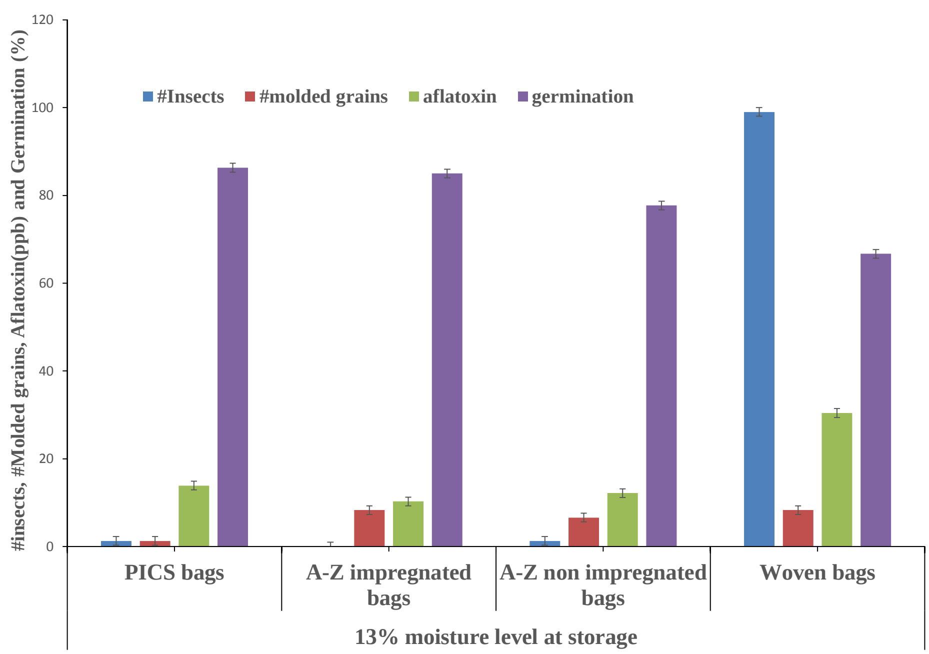

Figure17: Contamination, infestation, and quality of maize at 13% moisture content after three months of storage in hermetic bags in Velingara, Senegal

1.5.5 – Determine effectiveness of the Aflasafe treatment of maize on fungal populations and aflatoxin accumulation in hermetic storage – Dr. Woloshuk at Purdue is in the process of obtaining maize grown with Aflaguard (the US version of Aflasafe) for storage trials at Purdue.

<u>Activity 1.6 – Socio-Economic assessment of grain drying and storage alternatives for smallholder farmers, farmer associations, small scale grain traders and food processors in Senegal and Kenya.</u>

i. Description: To better understand interventions, technologies and educational ways for smallholder farmers, and traders to dry, store and sell better quality maize that is dry and free of mycotoxins and other contaminants
ii. Location: Kakamega, Kenya; and Velingara, Senegal
iii. Collaborators[5]: Jacob Ricker-Gilbert (Purdue, USA); Jonathan Bauchet (Purdue, USA); Hugo DeGroote (CIMMYT, Kenya); Moussa Sall (ISRA, Senegal); Ibrahima Sarr (ISRA, Senegal)
iv. Achievements:

(a) Socio-Economic assessment in Kakamega, Kenya

The realization by FPL researchers that a low-cost hygrometer can be used as an accurate maize moisture meter shows that there is a way to detect moisture content at a potentially affordable price. As a result, Purdue University, CIMMYT, and KALRO partnered on a market study to see if there is demand (willingness to pay) for the hygrometers from farmers and traders in the Kenyan maize market. The study took place in February and March of 2017 in Kakamega, Kenya. In total 305 farmers and 284 traders participated in an experimental auction using the Becker-DeGroot-Maschak (BDM) method where study participants bid on hygrometers and were required to buy them if they submitted a winning bid.

<u>Results:</u> Results from the auction suggest that both farmers and traders are willing to pay for the hygrometers a price that is above the current wholesale price. The mean bid for the hygrometer is $1.21 for farmers and $1.16 for traders, with both groups offering a median bid of $1.00 for the device (Table 1). These findings open the door for possible commercialization. Respondents report liking the accuracy of the hygrometer and its ability to generate a number that tells when maize is dry enough for safe storage along with the durability of the device as reasons for purchasing it (at common temperatures in Kenya, a relative humidity level at or below 65% indicates that maize is dry enough to be stored or sold).

Table 2: Participants' Willingness to Pay for Hygrometer

	Farmer	Trader
Mean (standard deviation)	$1.21 ($0.83)	$1.16 ($0.80)
Median	$1.00	$1.00

Note: Bids given in Kenyan Shillings (KES), US$1.00 = 100 KES.

Given the bids offered by respondents for the hygrometers and the proportion of people willing to purchase the device at each point, we find that the profit maximizing point for retailers to sell the device is about $1.90 per unit. At this price point, 25% percentage of respondents would be willing to buy the device (Figure 18).

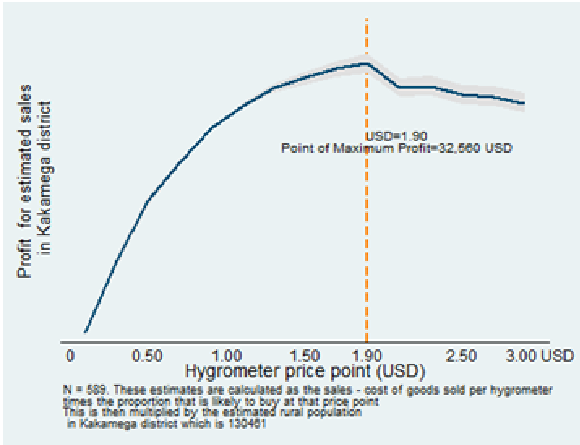

Figure 18: Profitability Analysis of Hygrometer

Next Steps/Commercialization Plan: The results of the auction have shown interest and willingness to pay for the hygrometers on the part of farmers and traders in Western Kenya. The team plans to use the input supply chain for the Purdue Improved Crop Storage Bags (PICS) that have recently been introduced and are starting to be adopted in Kenya as a way to promote and distribute the hygrometers. To that end, discussions are underway with Bell Industries who manufacture and distribute PICS bags in Kenya. Bell has expressed interest in distributing the hygrometers.

The next step is to conduct a pilot in August 2017 in which 1,000 hygrometers will be left on consignment with agricultural input retailers that are part of Bell's supply chain. The retailers will carry accompanying flyers and put up posters with information about the hygrometer and how to use it. Bell Industries will look into getting permission to classify each commodity as an agricultural input in order to gain import tax exemption. Simultaneously extension workers in areas where the piloting the hygrometer will occur will be trained on its use.

The goal is to utilize the information provided piloting step to make hygrometers available for retailing as soon as possible. The hygrometers are manufactured in China, but FPL currently purchases them through an online reseller. The belief is that if a bulk purchase is made directly from the manufacturer, the per-unit price of the hygrometer can be lowered below $0.90. Therefore, identifying and communicating with the manufacturer will be a top priority in the near future. This is extremely important because as the costs of distributing the hygrometer come down, the savings can be passed back to the end user leading to greater adoption of the device. This will ultimately help the Kenyan market offer maize that is of higher quality and safer to consumers. As such, the impacts on public health and post-harvest losses can be substantial.

(b) Socio-Economic assessment in Velingara, Senegal

Given the importance of maize for households in Velingara, the prevalence of aflatoxin in the area found in earlier FPL studies, and the limited resources of the smallholder population, FPL team setup an intervention to determine the most cost-effective way to prevent aflatoxin contamination and spread in smallholder drying and storage practices. In countries such as Senegal where there is no enforced regulatory limit on aflatoxin, households may not be aware of aflatoxin or have the means to prevent it. Previous research also suggests that drying maize on the dirt is one of the most likely points for fungal contamination.

First, a baseline survey was conducted in 210 villages (1,993 households) in May 2016. We then randomly assigned households in October 2016 to a control group (Group 1), or four treatment groups (Groups 2-5). All households were surveyed again in January/February 2017, to determine which households implemented recommended practices and the moisture content levels of their dried maize. Groups 2-5 (1,555 households) were trained on improved drying and storage practices. Groups 3-5 (1,177 households) were provided with hygrometers as a low-cost grain moisture verification tool. Groups 4-5 (799 households) received a 10m^2 plastic sheet as an alternative to drying their maize directly on the dirt. These sheets can sun dry ~200 kg maize over a given time period (likely 2-3 days). Purdue Improved Crop Storage (PICS) bags were provided to households in Group 5 (397 households) as a means of preventing insect contamination when the maize is stored. The total per household investment cost of our interventions was estimated, before labor costs, to be $6.62 – $9.37.

Initial Results: The project was able to conduct the second survey in January/ February 2017 with 99% of the households contacted at baseline. Very few households had ever received training on grain drying and storage, thus we see a large increase after the project interventions (Table 3).

Table 3. Summary of households surveyed and trained

	Households surveyed		Increase in training on grain drying and storage	
	Baseline	Jan/Feb 2017	Men	Women
1) Control	388	385	3%	1%
2) Training	393	386	94%	24%
3) + Hygrometer	397	385	94%	29%
4) + Tarp	407	405	97%	37%
5) + PICS bag	409	404	96%	31%

At baseline, few households knew that aflatoxin was toxic. Thus, knowledge of aflatoxin's toxicity among households rapidly improved with training (column 1). In addition, summary statistics indicate training was as important to reducing direct ground drying (column 2) as was receipt of a tarp. However, provision of a PICS bag was key to use of an improved storage container (defined as an improved granary, metal drum, airtight jerrycan, or PICS bag). Further analyses will clarify these observations (Table 4).

Table 4. Percent changes from baseline to after intervention

	% Change from baseline		
	Aflatoxin toxicity	Ground drying	Improved storage
1) Control	-8%	-6%	-3%
2) Training	36%	-16%	-4%
3) + Hygrometer	47%	-16%	-1%
4) + Tarp	39%	-15%	-3%
5) + PICS bag	40%	-23%	24%

Next step: The next step in this intervention is to return to Velingara in May of 2017 to collect maize samples and test them for aflatoxin. Reduction of aflatoxin is the ultimate impact against which we will measure the benefits of the different interventions. If and when we are able determine the most effective combination of training and technologies to reduce aflatoxin, we will work to promote those methods with extension and NGO's.

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

i) PROJECT I

i. Name: Food processing

ii. Description: Assessment of market demand and drivers for processed and nutritionally enhanced products, and development of processes and products with potential for the marketplace.

iii. Collaborators[5]: Bruce Hamaker - lead & Mario Ferruzzi (Purdue); Violet Mugalavai & Augostino Onkware (University of Eldoret, Kenya); Djibril Traore (ITA, Senegal); John Taylor & Gyebi Duodu (University of Pretoria); Hugo DeGroote (CIMMYT, Kenya)

iv. Achievements:

KENYA

(a) University of Eldoret:

1. The University of Eldoret Incubation Center was active in the 6-month period; trained 25 processors, 7 males and 18 females (Figure, 19) and participated in two exhibitions to demonstrate to the public naturally fortified instant cereal products developed at the Center.
2. They were active in creating partnerships with small scale industries that process natural fortificants so as to get the products at a lower price, and to reduce the final cost of the instant cereal flours. Partnerships were established with Organi Ltd., Kisii County, Kenya and the Nyapalo Farmers' Cooperative, Homabay County, Kenya, processors and farmers of orange fleshed Sweet potato (OFSP), respectively. The Incubation Center staff toured the Organi Ltd. processing plant observing the process of making OFSP puree and flour. Organi Ltd is now a regular supplier of OFSP products. Another partnership was established with CIP, through Dr. Jan Low (2016 World Food Prize Laureate) who provided the Incubation Center staff with advice on the use of OFSP as a fortificant.
3. Technologies transferred: One former trainee of the Incubation Center now sells fortified instant flour at her cereals shop and also makes instant porridge for her clients. Another trainee makes and sells sorghum-based baked products and snacks. The team, headed by Dr. Mugalavai, interacted with consumers and did further demonstrations on how to make instant thick and thin porridges. Consumers have high interest in the instant cereal products. Also, trainings (Figure 19) took place at the Incubation Center.
4. As an extension of the willingness-to-pay study done in the summer of 2016 (results reported below), an "in-home use" study was initiated in this project period. The objective is to understand how consumers react to instant flours when they use them in the home, and whether their willingness-to-pay changes. Instant flours of maize, and blends of maize and sorghum prepared at the Incubation Center are being used in the study. A pre-study done by Purdue PhD student, Emmanuel Ayua, showed that consumers appreciate blends of maize and sorghum, though as sorghum proportion increases to a high level, sensory attributes of ugali decrease even though appearance is judged high. This suggests that consumers judge sorghum incorporation very positively despite its comparatively poorer taste and texture (Figure 20).

Figure 19. Participants in the training session at University of Eldoret Incubation Center

Presentations and publications:

1. FPL participated in an exhibition at the Integrated Nutrition Conference organized by Catholic Relief Services in Nairobi, in November, 2016. Dr. Mugalavai interacted with consumers and did demonstrations on how to make instant thick and thin porridges.
2. FPL participated in the post-harvest Congress held in Nairobi in late March, 2017 and Dr. Onkware presented a paper entitled "Technology-based Incubation Centres for Developing Affordable Nutritious Foods"

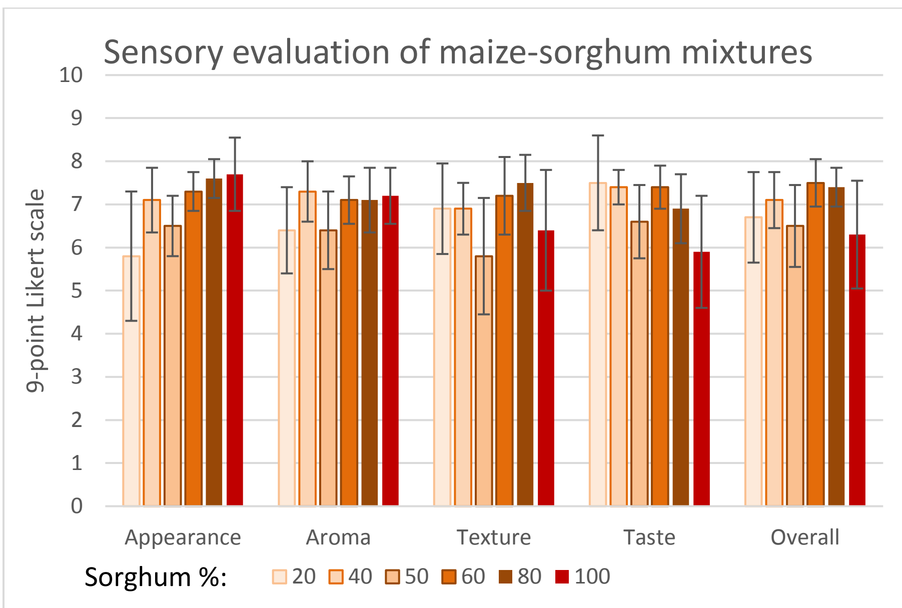

Figure 20. Consumer liking of ugali with increasing levels of sorghum mixed with maize.

<u>(b) CIMMYT:</u>

1. Consumer study in Touba, Senegal

   Data analysis for the study (previously presented at the AAAE conference in Addis Ababa, Sept. 2016) was finalized. The results showed that there is a potential market in Senegal for instant and fortified cereal food products, but likely in the higher income and education groups. The increase in cost needs to be compared to the premiums consumers are willing to pay. The next step is to test the new and promising products in pilot markets, with target consumers. A manuscript titled "Measuring consumers' interest in instant fortified pearl millet products - a field experiment in Touba, Senegal" by Hugo De Groote, Sarah W. Kariuki, Djibril Traore, John R.N. Taylor, Mario

Ferruzzi, and Bruce R. Hamaker has been submitted to the Journal of the Science of Food and Agriculture.

2. Acceptance and willingness to pay for fortified products in Eldoret, Kenya
Data analysis for this study (conducted in July 2016 and reported in previous reporting has been completed and a manuscript is being prepared. The results (Figure 21) showed consumers' willingness to pay a premium for mixed flours (27%), for instant flour 19%), and for fortification (25%), after receiving information about products. The conclusion is that there is a potential market in Kenya for instant cereal food products. However, the natural fortificants used need to be carefully selected, and their performance and costs compared to artificial micronutrient premixes. The increase in cost needs to be compared to the premiums consumers are willing to pay.

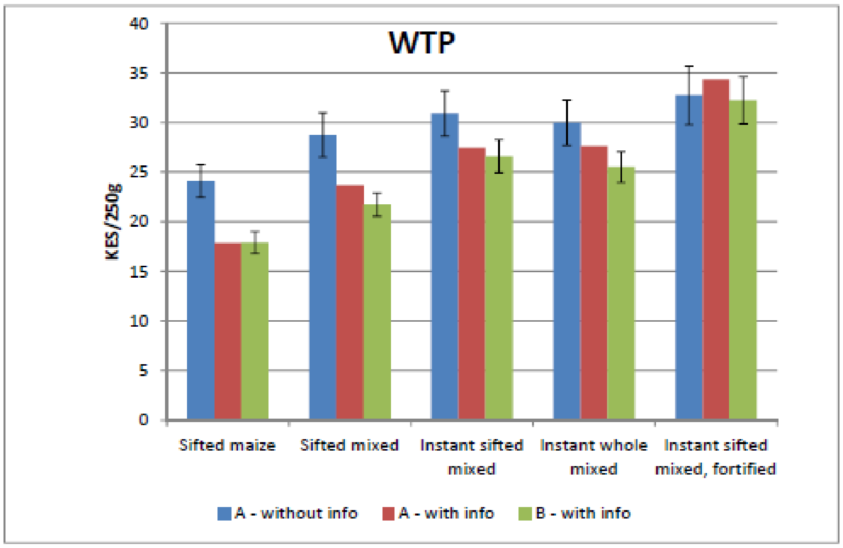

Figure 21. Willingness to pay for different cereal products in Eldoret, Kenya

3. Consumer study on acceptance and willingness to pay for instant fortified millet products in Dakar. The study was conducted in Dakar, Senegal, in March 2017, with 300 consumers drawn from the suburbs of Dakar (Guediawaye, Thiaroye, Pikine, Derkle, Geule Tapee, Ouagou Niaye). Five products were evaluated: 1) sifted millet flour, 2) instant sifted millet flour; 3) instant whole millet flour, 4) instant whole millet flour fortified with micronutrients, 5) instant whole millet flour fortified with micronutrients, carrots and bouye. Study data is being analyzed.

SENEGAL

<u>(a) Institut de Technologie Alimentaire (ITA)</u>

1. ITA was involved in the following activities: 1) investigating locally available nutrient-rich value chains (i.e., baobab fruit flour/bouye, moringa leaves, papaya, mangoes, cowpea and peanut) for enhancement of the nutritional value of processed products from local cereals (millet, sorghum and maize), and 2) strengthening partnerships with women entrepreneurs of the country (primarily Mme. Mbacke in Touba).

2. Weaning food developed from millet, cowpea, peanut butter, baobab flour (bouye), carrots, and vitamin and mineral mixes were further optimized at ITA. These products are ready for transfer to processors.

(b) University of Pretoria: Sensory quality of products.
In support of the porridge product development activities, the shelf-life of extruded pearl millet-based instant porridge flour is being evaluated using the "Survival Analysis" technique. The technique involves analysis of time-to-event data. Such data describe the length of time from a time origin to an endpoint of interest. The event of interest here is onset of rancidity in the flours stored at different temperatures, and the endpoint is desired shelf-life of the flour product. The work is being undertaken by PhD student Mr. Isiguzoro Onyeoziri under the supervision of Prof. Riette de Kock and Prof. Taylor.

(c) Purdue University: Impact of extrusion on lipid oxidation and acceptability of whole grain pearl millet (Pennisetum glaucum) flours.
Whole pearl millet utilization is desirable due to its comparatively high iron and zinc levels, particularly the biofortified millets. The major constraint for whole grain is poor product stability issues during storage. Whole pearl millet has a large content of unsaturated fats, which make it susceptible to development of undesirable off-flavors during storage. Whole conventionally milled (control), whole extruded, decorticated conventionally milled and decorticated extruded flours, were stored at 4, 20, and 35 °C for 18 weeks. Oxidative rancidity, peroxide and aldehydes values, and free fatty acids, the lipolysis products, were evaluated at baseline and weeks 4, 8, 12 and 18. Additionally color and quantitative sensory (n=75) was performed. There were no statistically significant ($P < 0.05$) differences between treatments in free fatty acid or aldehyde content at week 0 (baseline). A significant increase of free fatty acids was observed only in conventionally milled flours stored at 20 °C, but not extruded flours indicating that extrusion halted lipolysis. Peroxide values were statistically higher for both extruded flours at baseline and remained significant at week 18. A trend in the increase in aldehyde concentration occurred over 18 weeks in all treatments. Despite an increase in peroxide value in extruded flours, there was not higher aldehydye development compared to the native flours. Sensory tests revealed that porridge prepared with whole extruded flour had higher flavor, texture and color scores compared to decorticated extruded, and decorticated conventionally milled was ranked the highest. Extrusion prevented the development of off-flavors from free fatty acids, and improved sensory attributes. Thus, improvement regarding oxidative rancidity is possible. Use of this technology to process whole indigenous African grains is a feasible strategy to improve nutritional value of foods.

ii) **PROJECT 2:**

i. Name: Nutritional studies
ii. Description: Screening of nutrient-rich plant materials for use in consumer based food products in Senegal and Kenya.
iii. Location: Purdue, USA, Dakar and Touba, Senegal, and Eldoret and Nairobi, Kenya
iv. 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).
v. Achievements:

(a) Purdue University:
In order to understand the impact of extrusion on quality parameters and micronutrient recovery from fruit/vegetable-cereal blends, wholegrain (WG) millet (Senegalese Souna var.) was blended with solar-dried powdered carrot (CRT) at 15% and 5% of Adansiona digitata (baobab) or Moringa oleifera (moringa). All blended products were adjusted to

~35% moisture prior to extrusion on a Technochem Mini-Extruder© (900rpm; Final Temp = 99-121°C). Instantized products were assessed for quality attributes [color, water absorption and solubility index, pasting properties (RVA), provitamin A and total carotenoids recovery (LC). Provitamin A recovery was 68.45% in WG/CRT/baobab compared to 60% recovery in WG/CRT and 90.34% in WG/CRT/moringa, the highest among the extrudates. Samples with WG/CRT/moringa provided high content of total carotenoid and lutein with 5.4 and 38%, respectively as contributions from moringa (Figure 22).

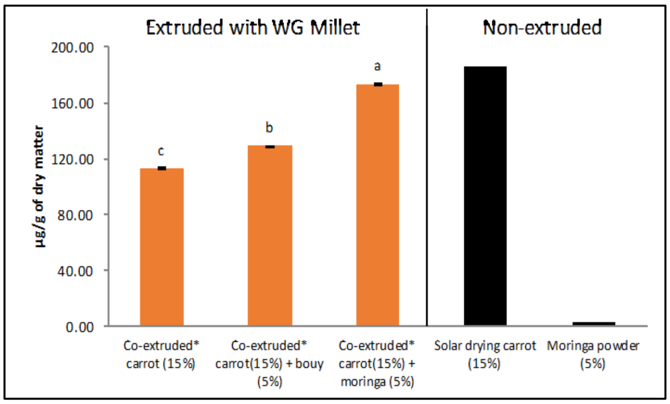

Figure 22. Recovery of Provitamin A carotenoids following extrusion of carrot and WG millet with inclusion of bouye and moringa (5%). Panel on right indicates the starting contributions of carrot and moringa to total provitamin A carotenoid content prior to extrusion. Orange bars indicate amount remaining after extrusion of blends. Results suggest that formulation with baobab (bouy) and moringa may stabilize carotenoids through extrusion process. Values represent n=3 replicates.

Extrusion also impacted physical properties. Baobab (5%) had an impact on WG millet product color with an overall increase in lightness of the whole grain product (Figure 23). Co-extruded WG/CRT had greatest impact on browning index and chroma values, respectively from 39 (WC Control) and 21.5 to 156 and 57.5 (WG/CRT/ baobab) ($P<0.05$). Water solubility and absorption indexes were significantly ($P<0.05$) increased by inclusion of CRT and baobab in WG extrudates.

Both boabab and moringa inclusion with carrot altered the pasting temperatures of final products (Figure 24). Also these blends decreased the final viscosities of the WG extrudates. High hot paste viscosity was observed in extrudates made from WG/CRT/baobab samples (1600 CP). Extruded WG millet and CRT with or without moringa decreased the hot paste viscosity significantly (500 to 700 CP). These data suggest that production of instantized fruit/vegetable millet blends can be achieved with promising recovery of provitamin A carotenoids.

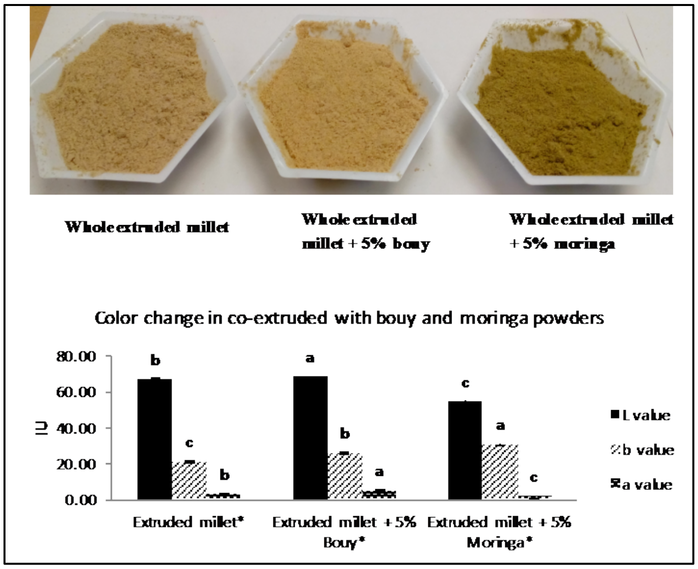

Figure 23. Changes in color parameters of co-extruded WG millet with baobab and moringa (5% each). A subtle but significant change in L (lightness) was observed with inclusion of baobab while a darkening was observed with moringa. Values represent n=3 replicates.

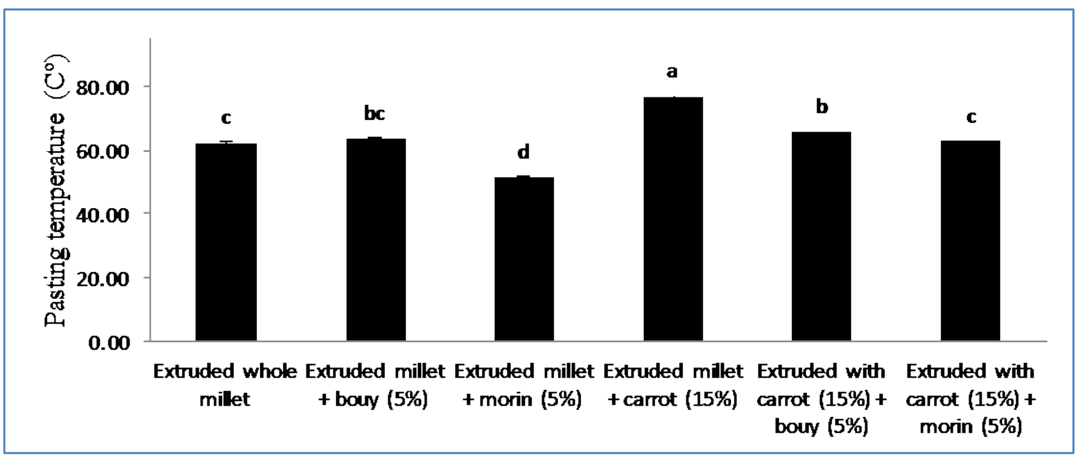

Figure 24. Pasting temperature of extruded WG millet is impacted by inclusion of carrot, baobab and moringa.

(b) University of Pretoria:

I) Natural fortification with moringa leaves and baobab fruit pulp

In support of the project activities in Senegal and Kenya to improve the micronutrient nutritional quality of the cereal-based instant porridge products, the effects of adding 5% and 15% dried moringa leaves(M) and baobab fruit pulp (B) to instant whole pearl millet instant porridges on iron and zinc bioaccessibilities (in vitro dialysability) was determined (Figure 25). The work was carried out by MSc student Renee van der Merwe under the supervision of Dr. Kruger and Prof. Taylor.

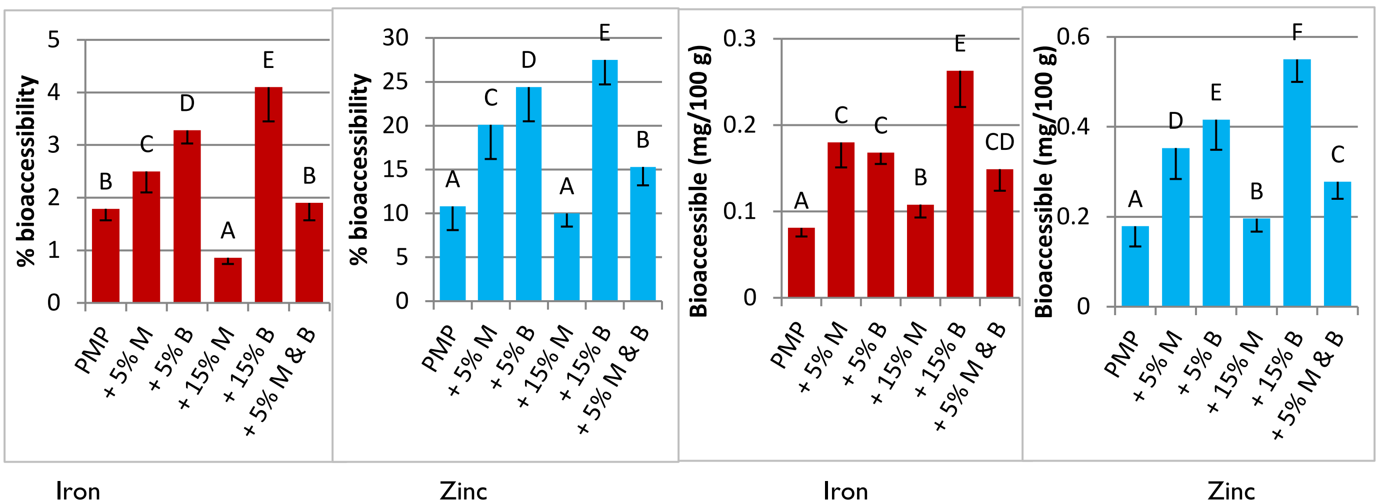

Figure 25. Effects of addition of moringa and boabab to a pearl millet-based porridge (PMP) (30% provitamin A source added) at 5 and 15% on the percentage (%) and amount (mg/100 g) of bioaccessible iron and zinc

Values are reported as Mean ± 1 Standard deviation (percentage difference from blend Co PMA). Blends were ~~analysed~~analyzed in triplicate (n = 3), outliers were removed using Grubb's test for outliers. Means followed by different letter superscripts differ significantly according to Fisher's LSD test (P ≤ 0.05). PMP: Control pearl millet + provitamin A, M: moringa, B: baobab.

Despite the high iron content of the Moringa (58 mg/100 g, db) its addition to the pearl millet-based porridge was the least promising with respect to increasing the iron and zinc bioaccessibility. Its addition at 5% resulted in slightly lower improvements in iron and zinc bioaccessibility compared to baobab (5%), and at 15% iron bioaccessibility was decreased and zinc bioaccessibility was similar to that of the pearl millet-based porridge. In contrast, addition of baobab at 15% had a much larger positive effect, with substantial percentage increases (compared to pearl millet-based porridge) in the percentage and amount of bioaccessible iron (129 and 154%, respectively) and zinc (225 and 181%, respectively). The findings from this research strongly indicate that baobab fruit has the potential to substantially improve iron and zinc bioavailability in cereal-based foods. This is probably due the high contents of ascorbic acid and fruit acids like citric acid in baobab fruit. This hypothesis is now being intensively investigated.

ii) Natural fortification with grain amaranth

In support of project activities in Kenya to improve the micronutrient and protein nutritional quality of cereal-based porridge products, the effects of different methods of souring on phytate (mineral absorption inhibitor) content and the bioaccessible Fe and Zn contents of porridges were investigated. The souring methods used were: traditional

"sourdough-type" fermentation involving inoculation by back-slopping; inoculation with an indicative prebiotic Lactobacillus plantarum culture; and acidification using commercial lactic acid. Porridges were prepared using sorghum, amaranth grain, and sorghum-amaranth grain composite flours (Table 5). The work was carried out by PhD student Mr Adeyemi Adeyanju under the supervision of Prof. Duodu, Prof. Taylor, and Dr. Kruger.
Overall, all the three methods of souring substantially reduced phytate content and increased bioaccessible Fe and Zn in the porridges. Thus, depending on the desired application, either traditional sourdough type fermentation, inoculation with a fermentative probiotic type bacteria culture or simple acidification with lactic acid will be equally highly effective in improving iron and zinc bioavailability in cereal- and the protein-rich pseudocereal porridges.

Table 5, Effect of lactic acid fermentation and lactic acid (LA) acidification on phytate content and dialysability of Fe and Zn of porridges prepared from sorghum, amaranth and sorghum-amaranth composite flours

Sample	Phytate (mg/g db)	Dialysable Fe (mg/100 g db)	Dialysable Zn (mg/100 g db)
Sorghum			
Cooked	10.98 ± 0.37	0.12 ± 0.01	0.50 ± 0.03
Fermented* and Cooked	3.61 ± 0.36	0.35 ± 0.01	0.62 ± 0.03
Fermented♠ and Cooked	3.22 ± 0.18	0.28 ± 0.01	0.62 ± 0.10
LA# acidified and cooked	3.80 ± 0.19	0.30 ± 0.01	0.64 ± 0.01
Amaranth			
Cooked	18.22 ± 0.18	0.18 ± 0.04	0.17 ± 0.03
Fermented* and Cooked	3.46 ± 0.18	0.42 ± 0.02	0.26 ± 0.03
Fermented♠ and Cooked	3.83 ± 0.19	0.41 ± 0.04	0.29 ± 0.03
LA acidified and cooked	4.42 + 0.18	0.85 ± 0.01	0.50 ± 0.02
Sorghum:Amaranth (50:50)			
Cooked	16.69 ± 0.19	0.10 ± 0.01	0.18 ± 0.01
Fermented* and Cooked	3.62 ± 0.37	0.47 ± 0.01	0.26 ± 0.01
Fermented♠ and Cooked	2.48 ± 0.18	0.46 ± 0.01	0.34 ± 0.01
LA acidified and cooked	4.20 ± 0.18	0.42 ± 0.01	0.37 ± 0.01

* Fermentation with *Lactobacillus plantarum*; ♠ Fermentation with a backslopped inoculum

Presentations and Publications:

1) Kruger, J. (2016). Replacing electrolytic iron in a fortification-mix with NaFeEDTA increases both iron and zinc availabilities in traditional African maize porridges. Food Chemistry, 205, 9-13.
2) Van der Merwe, R., Taylor, J.R.N. and Kruger, J. (2017). Mineral-rich plant foods has the potential to increase iron and zinc bioavailability from an instant cereal-based porridge. 3rd Hidden Hunger Conference. Stuttgart, Germany. March 2017.

Lessons Learned:

1) Surprisingly high increases in *in vitro* bioaccessibility of iron and zinc were observed when baobab was added to whole grain instant millet porridges. Thus, there is the promise of increased bioavailability of these critical micronutrients. Plans are underway to test this in an acute human study in the fall of 2017. This finding could have broad implications for delivery of these minerals in other foods.

2) A sourdough-type fermentation approach, whether done in a traditional way or through addition of a culture or simply by adding lactic acid, reduces phytate and increases bioaccessible iron and zinc.
3) Formulation of millet instant products with baobab (bouy) and moringa may stabilize carotenoids to extrusion processing. Co-extrusion of millet with the nutrient-rich plant materials is a good way of retaining added carotenoid nutritional value.

V) HUMAN AND INSTITUTIONAL CAPACITY DEVELOPMENT[8]

a) Short-term training

Activity 3.1: Workshop on food processing technologies

i. Description: Conduct training workshops for food processors in Kenya.
ii. Location: Eldoret, Kenya
iii. Collaborators[9]: Violet Mugalavai & Augostino Onkware (University of Eldoret, Kenya);
iv. Achievements:
   Twenty five processors were trained: 7 males and 18 females in food technologies at UoE Food processing Training and Incubation Centre. They were given hands-on training on how to use the extruder to make instant cereal flours and on baking skills. They are in the process of incubating their product ideas.

[8] 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.
[9] Provide institutional affiliation and country.

b) Long –term training

Name	Sex	University	Degree	Major	Program End Date[10] (month/year)	Degree Granted [11] (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	2018	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	Yes	USA
Brett Lane	Male	Purdue University	MS	Plant Science	2016	Yes	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	Yes	Nepal

** Students were supported on research only

[10] Anticipated graduation date or end of program support
[11] Indicate if program support resulted in a degree

VI) INNOVATION TRANSFER AND SCALING PARTERSHIPS[12]

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 – Trademark Applications. JUA Technologies International has been given exclusive license by the Purdue Research Foundation for the multipurpose solar dryer also known as the multipurpose solar dehydrator, and drying or dehydration tray. Dryer and dehydrator will be used interchangeably in this document. JTI has filed three trademarks with the U.S Trademark and Patent Office (USPTO) for the following products:
   U.S. Trademark Serial No. 87/316,091 for "DEHYMELEON"
   International Class 11 for "solar powered food dehydrator"
   U.S. Trademark Serial No. 87/316,102 for "DEHYMELEON"
   International Class 07 for "solar powered electricity generators"
   U.S. Trademark Serial No. 87/316,107 for "DEHYTRAY"
   International Class 21 for "basket for dehydrating food"
   Filing Date: January 27, 2017.

   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: Two drying technologies – the drying trays or baskets (5 kg wet maize per tray), and (2) a multipurpose solar dehydrator (45 kg wet maize per batch).

   iv. Technologies transferred N/A

   v. Technologies scaled N/A

b) Commercialization of hygrometer as a low-cost moisture measuring device. FPL is exploring options to commercialize the hygrometer for measuring grain moisture

   i. Steps taken – In early 2017, the FPL team studied the willingness to pay for the hygrometer among farmers and trades in Kenya. The Purdue team interviewed 580 people, including 305 farmers and 284 traders, from the Kakamega district in Kenya. The mean willingness to pay for the hygrometer was US$1.21 for farmers and US$1.15 for traders. The median willingness to pay for the hygrometer was $1 for both farmers and traders. In an analysis of the supply side of the market, the optimal retail price of the hygrometer was estimated to be about US$1.90.

   ii. Partnerships made: A local private company in Kenya (Bell Industries), which markets other Purdue technologies in Kenya is interested in marketing the hygrometer. FPL is in also discussions with the Horticulture Innovation Lab about a joint commercialization effort throughout Africa for the hygrometer and the Hort. IL "Dry Card" which is a paper strip for measuring grain moisture. Purdue is in discussion with Global Good, a global invention company through a collaboration between the Bill and Melinda Gates Foundation and Intellectual Ventures to redesign the hygrometer for moisture measurement.

   iii. Technologies ready to scale: Hygrometer and a protocol for its use to measure grain moisture content. (Ptotocol: a handful of grain is placed in a small, sealable plastic bag with the hygrometer. Moisture equilibrium is established within 15-30 minutes. If the relative humidity reading is above 65%, the grain is too wet for safe storage. Below 65% RH, the grain is ready for storage).

   iv. Technologies transferred: N/A

   v. Technologies scaled N/A

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

c) Transfer of extrusion technology to Kenya and Senegal.
   i. Steps taken – Two low-cost small scale extruders have been placed in Senegal (one at ITA and the other at local food processor's facility) and one in Kenya at the University of Eldoret. Consumer studies on acceptance and willingness to pay for instant flour products (fortified and non-fortified) have been conducted in both countries and results show a strong interest and willingness to pay for the products. ITA has developed many
   ii. Partnerships made: A local food processor, Mme. Astou Gaye Mbacke received the FPL extruder to use for her own processing and to train other local processors. Since receiving the extruder in March 2016, she has received orders for instant products beyond her capacity to supply. There is strong interest too within the Senegalese government to support purchase and installation of more extruders including those with higher capacity than the mini-extruder.
   iii. Technologies ready to scale: Extrusion technology with capability of producing a wide range of instant-flour based products
   iv. Technologies transferred N/A
   v. Technologies scaled N/A

VII) 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.
In Senegal two complete individual protection equipment sets were acquired for working with the insect impregnated A to Z Textile hermetic bags. The study began in November 2017. There is a protocol in place for safe disposal of the grain and bags at the end of the study.

VIII) 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.

IX) 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 technical and 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 AC annual conference call is scheduled for August 22, 2017. The project also holds an annual half-day WebEx meeting; this year's meeting is scheduled for July 12, 2017.

X) OTHER TOPICS[13]

Dr. Cheryl O'Brien, Assistant Professor, San Diego State University, a gender consultant FPL has consistently provided input and guidance for project teams on gender issues. 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. A total of 16 Focus Group Discussions (FGDs) with men and women farmers separately were held in the two countries. A draft report was prepared by Dr. O'Brien in January 2017, which included data coded into tables, disaggregated by gender, based on major findings from the 16 FGDs. The results show diverse and often conflicting perspectives among men and women in both countries on roles, rights, responsibilities, entitlements, and obligations. Overall, men generally made the decisions about harvesting and the selling or storing of crops, particularly maize. Women spouses were sometimes consulted regarding these decisions, but ultimately the final decisions were made by their husbands or male heads of households. The way income was earned and spent within a household varied from village to village and perceptions of this praxis also varied depending on gender. Men tended to believe there were little or no disagreements in regards to this process, regardless of the way income was handled in their households. Women tended to express that disagreements happened and reaching a solution could extend to involve the village leaders such as the chief. Women who expressed land ownership were extremely rare, and the answers varied based on statutory or customary laws. A manuscript is being prepared for publication in peer-reviewed journal. Also, Dr. O'Brien attended Gender in Agriculture Partnership webinar "Closing the gender data gap for agricultural policy and investment" in the fall of 2016 and communicated with information with FPL team members. O'Brien is also collaborating with Kansas State University's FTF PHL to strengthen gender integration across its teams in Ethiopia, Guatemala, Ghana, and Bangladesh and provides a linkage between the two innovation labs with regard to gender issues.

XI) ISSUES AND HOW THEY ARE BEING ADDRESSED[14]

a) FPL lost two key staff members: Ms. Laura Bergdoll, Business Manager and Ms. Heather Fabries, Program Manager in February 2017. Arrangements were made for their replacements as follows: Ms. Beth Siple is the new Business Manager and Ms. Julie Hancock is the Program Manager. The project is on track despite these disruptions.
b) There was a two month delay in the release of 2016/17 fiscal year funding from USAID, which delayed the start of project activities. This problem was exacerbated by the fact that the USAID added new requirements to anti-trafficking clause ("C20: Trafficking of persons") that rendered Purdue non-compliant, which caused Purdue not to sign the agreement. Purdue spent additional time putting systems in place to ensure compliance before signing the agreement. The cumulative effect was a delay in the start of activities. The program is generally back on track after all the issues were resolved.
c) A few FPL sub-awardees have been slow in providing receipts to the Purdue business office for funds advanced to them. Continued improvement in communication between Purdue and the sub-awardee business offices has helped to mitigate the problem considerably.

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

XII) 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 tropics. 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. Overall, the first two years of the project focused on technology development, on-station testing, and modification. In this fiscal year (Year 3), emphasis is on field-testing and technology adaptation to environments of operation and selection of viable technologies for adoption. In years 4 and 5, the program will focus on aspects of technology adoption, scale-up, and assessment of potential for commercialization of viable technologies. 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.