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

**ANNUAL REPORT**

**October 31, 2018**

LEAD UNIVERSITY

Purdue University

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LIST OF COUNTRIES WHERE THE PROJECT WORKS

Kenya and Senegal

LIST OF ORIGINAL 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
- ***Sénégal:*** Institut de Technologie Alimentaire and Institut Sénégalais 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 | Alpha (α) carotene |
| AC | Advisory Council |
| ACRE | Agronomy Center for Research and Extension |
| ASABE | American Society of Agricultural and Biological Engineers |
| ASTM | American Society for Testing and Materials |
| BC | Beta-carotene |
| CLM | Cellule de Lutte Contre la Malnutrition (National Committee for Control of Malnutrition) |
| CIP | International Potato Center |
| CRT | Powdered carrot |
| DTI | Dairy Technical Institute |
| DDL | Development Data Library |
| DMP | Data Management Plan |
| DOIs | Digital Object Identifiers |
| DV | Daily Value |
| FGDs | Focus Group Discussions |
| FPTIC | Processing and Training Incubation Center |
| FPL | Innovation Lab for Food Processing and Post-harvest Handling |
| JTI | JUA Technologies International LLC. |
| KALRO | Kenya at the Kenya Agricultural and Livestock Research Organization |
| KEBS | Kenya Bureau of Standards |
| KCEP | Kenya Cereal Enhancement Programme |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics |
| ISRA | L'Institut Sénégalais de Recherches Agricoles |
| IITA | International Institute of Tropical Agriculture |
| ITA | Institut de Technologie Alimentaire |
| MC | Moisture content |
| NC | North Carolina |
| NCA&T | North Carolina A&T State University |
| NIST | National Institute of Standards and Technology |
| OFSP | Orange-fleshed sweet potato |
| PICS | Purdue Improved Crop Storage bags |
| PHL | Post-Harvest Innovation Lab, Kansas State University |
| PMP | Pearl millet-based porridge |
| PCR | Polymerase Chain Reaction |
| POD | Picosolar crOp Dryer |
| PPB | Parts per billion |
| PURR | Purdue University Research Repository |
| RDA | Recommended Daily Allowance |
| RH | Relative Humidity |
| SC | Steering Committee |
| UNICEF | United Nations International Children's Emergency Fund |
| USPTO | United States Patent and Trademark 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, 2017 to September 30, 2018. The FPL continued to make progress in all key aspects of the program including drying, moisture detection, storage, processing and nutrition, with gender and the environment as cross-cutting themes. Under the drying and storage component, there was increased focus on training and dissemination of promising technologies. Over 2800 farmers, traders, and extension staff received training on best practices for drying and storage. Commercialization of the hygrometer alongside Purdue Improved Crop Storage (PICS) bags was initiated, in collaboration with the local private sector in both countries. Strategies for cost-effectively reducing aflatoxin contamination in stored maize were identified, tested, and disseminated to farmers. Under the processing and nutrition component, market drivers for commercial food products were identified for use in optimizing blended product formulations for the project. Commercially viable micronutrient-rich native fruits and vegetables ingredients and product formulations for instant cereal products blends were developed. Additionally, extruded whole grain flours showed reduced starch digestibility compared to decorticated flours. These characteristics give the whole grain flour-based products added benefits of slow starch digestibility and moderated glycemic response. The Government of Senegal's continued interest in the project was manifested through a high-level meeting to discuss increasing extrusion capacity and scaling-up of the "Hub and Spoke" Incubation/Innovation model to other regions in Senegal. The research, outreach, and monitoring and evaluation efforts provided a platform for strengthening existing public-private partnerships and establishing new ones.

## II) PROGRAM ACTIVITIY HIGHLIGHTS[2]

- Testing the impact of pre-harvest biocontrol treatment to reduce post-harvest aflatoxin accumulation during the drying period.
- Testing cobalt chloride humidity sensor strips to obtain a tight color break (from blue to pink) at 65% relative humidity as a cheap and effective method to estimate moisture content.
- Study to estimate demand for low cost moisture detection devices (Hygrometer and DryCard) by farmers and traders in Kenya.
- Initiated commercialization efforts for the hygrometer method for measuring moisture alongside Purdue Improved Crop Storage (PICS) bags, in collaboration with the local private sector in Kenya and Senegal.
- Study of the economics of roadside drying for use as the baseline against which to compare economic performance of improved dryers (solar and others).
- Evaluation of performance of the redesigned Pico CrOp Dryer (POD), a low-cost on-farm solar grain dryer for smallholder farmers.
- Mapping exercise for qualitative and semi-quantitative descriptive analysis of commercial products to help optimize FPL product formulations for Kenyan market.

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

- Five variations of extruded instant cereal products developed at the University of Eldoret's Food Processing and Training Incubation Center were submitted and certified for production by the national certifying body, Kenya Bureau of Standards (KEBS).
- Studies on effects of extrusion on shelf-life, sensory attributes, phytate reduction, and starch digestibility of pearl millet-based flours and porridges.
- Study conducted to determine optimum conditions for using the extruder in resource-limited conditions (mainly energy for extrusion and drying)
- Progress has been made in the translation of test formulations of cereals and nutrient dense plant material blends to commercial versions of extruded products for Senegal and Kenya.
- Study on natural provitamin A fortification of sorghum flour with orange fleshed sweet potato showed that both conventionally cooked and extrusion cooked instant porridge can make a significant contribution to the Vitamin A requirements of at-risk groups.
- Advanced plans for a human subject clinical study on hypothesized improvement of iron bioavailability in the FPL-generated products.
- Training farmers, traders, extension staff, and processors on promising FPL technologies and innovations in all areas of research.
- Strengthened existing and established new public-private partnerships in support of research and outreach activities:
    - Purdue, CYMMYT-Kenya, and KALRO continued partnering with Bell Industries, a local company in Kenya, which markets other Purdue technologies and is test marketing the hygrometer. Bell Industries participated in the training workshops.
    - Global Good (a collaborative effort between Bill Gates and Intellectual Ventures to address some of humanity's toughest problems through the power of invention) continues to work on refining and improving the hygrometer and plans to have a new prototype of the device ready for market testing by the end of 2019.
    - Purdue partnered with various organizations to train food processors in Senegal including: US Government funded projects (USAID-ERA and USDA-CLUSA/PSEM), World Food Programme; and Senegalese government authorities.
    - Purdue and ITA worked to strengthen the partnership with Touba Darou Salam Cereal Processing Unit., owned by Mme. Mbacke, a key local partner. Purdue and ITA continue to seek additional funding to expand processing to rural Senegal through the "Hub and Spoke" Food Innovation system.
- Participated in various conferences, exhibitions and trade fairs to demonstrate and promote effective technologies, and published peer-reviewed journal articles.

## III) KEY ACCOMPLISHMENTS[3]

- Approximately 3000 farmers, traders, extension staff, and food processors received training on promising FPL technologies.
- Product formulations (instant/conventional and fortified/non-fortified) were developed and optimized for the Kenyan and Senegalese markets.
- Five variations of instant cereal products, developed and processed at the University of Eldoret's Food Processing and Training Incubation Center (FPTIC), received certification by Kenya Bureau of Standards (KEBS), the national product certifying body in Kenya.

[3] Concise statement of achievements, linked to relevant section of annual work plan 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.

- Descriptive work on blended and acidified commercial products suggest that many of them fall within a narrow range of attributes that closely align with FPL formulations.
- Effects of extrusion on pearl millet-based flours and porridges were determined, including:
    - Increased shelf-life, improved sensory attributes, and reduced phytates (anti-nutritional factors)
    - Reduced starch digestibility in whole grain flour (compared to decorticated flours), which gives added benefits of slow starch digestibility and moderated glycemic response from the products.
- 27 graduate students have been recruited since program inception: 14 male and 13 female; 15 Ph.D. and 12 Masters. Four of the students are supported on research only (no tuition). The students come from Kenya, Senegal, Ethiopia, Uganda, Botswana, Nepal, Nigeria, South Africa, Ecuador, China, Pakistan, and USA.
    - Four female students were added to the program during the reporting period: three at Purdue and one at University Pretoria (one PhD and 3 MS).
    - Eight students have graduated from the program (6 male and 2 female/ 4 MS and 4 PhD). Six returned to their countries and 5 of them are known to be working. One was a US citizen and now works for a non-profit organization in the US.
- Fourteen peer-reviewed papers in total have been published by various researchers on the project.

IV) Theory of Change and Impact Pathway(s)

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

**Impact pathway**:

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

V) 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 farmers, and 2) Food processing and nutrition involves development of high quality, market-competitive food products, (including products with improved nutrition) and dissemination through "Hub and Spoke" Innovation centers. Building of local capacities (human and institutional) and building of partnerships among the public and private sectors, both domestic and international, are also major components of the project. Gender and environment are taken into account at all stages of the project cycle.

VI) 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: Testing effect of aflatoxin biocontrol treatment on reducing postharvest aflatoxin accumulation</u>**

i) Description: to test impact of pre-harvest biocontrol treatment on reducing post-harvest aflatoxin accumulation during the drying period.
ii) Location: West Lafayette, USA
iii) Collaborators[5]: Charles Woloshuk and Sharon Kinyungu (Purdue)
iv) Achievements: Results show that higher moistures result in more rapid growth of fungi and an increase in kernel infection and the populations of A. flavus strains also increase at the higher moisture.
v) Presentations and Publications: Kinyungu S.W. and Woloshuk C.P., 2018. Efficacy of pre-harvest Aspergillus flavus biocontrol treatment on reducing aflatoxin accumulation during drying (Poster presentation at the 2nd African Symposium on Mycotoxicology in Kenya, June 2018)

This study addresses the potential problem of aflatoxin accumulation in maize during the postharvest handling and drying period. Often this period is delayed because of rain and reduced solar conditions, which subjects the high moisture maize to conditions that favor the growth of *Aspergillus flavus* and aflatoxin accumulation. We hypothesize that the benefits of treatment of maize fields with biocontrol strains of *A. flavus* to reduce pre-harvest levels of aflatoxin will carry over into the postharvest handling and drying period. Efforts to test this hypothesis with Aflasafe-treated grain in Kenya was blocked by the International Institute of Tropical Agriculture (IITA). Therefore, the experiments were moved to the US where two similar commercial biocontrol products (Aflaguard and AF36) are sold. Grain from Texas and North Carolina from (NC) fields treated with AF36 and Aflaguard, respectively, was used. Untreated maize from fields at both locations was also obtain. The maize was conditioned to a moisture content (MC) of 20% and stored in jars for 6 days. The maize was sampled on days 0, 2, 4, and 6. Aflatoxin was not detected in any of the field samples at the start of the storage. However, after 6 days of incubation at 20% MC, the average aflatoxin concentration in the Aflaguard-treated grain increased to 211 µg/g of maize and was 77 µg/g of maize in the non-treated. Aflatoxin in the AF36-treated grain increased to 11 µg/g after 6 days, while no aflatoxin was detected in the non-treated Texas grain. The *A. flavus* from the grain was isolated and characterized. During the

[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.

six days of storage, the number of *A. flavus* colonies increased in both biocontrol-treated and non-treated field samples. In the initial samples from NC, *A. flavus* infected 2% of the kernels from both the Aflaguard-treated and non-treated. At day 6, infection increased to 35% and 39% of the kernels, respectively. The samples from Texas followed a similar trend. The AF36-treated grain increased from 0% to 20% of the kernels infected with *A. flavus*. In the non-treated grain, 1% of the kernels were initially infected with *A. flavus* and increased to 7% by day 6. These results indicate that the fungus rapidly spread at 20% MC. Isolates of *A. flavus* from infected kernels were tested for ability to produce aflatoxin in culture. These included 49 isolates from AF36-treated and 47 isolates from non-treated from Texas and 101 Aflaguard-treated and 86 non-treated from NC. From the Texas fields, 18% of the AF36-treated isolates were aflatoxigenic compared to 13% of the non-treated. From the Aflaguard-treated sample from NC, 17% of the *A. flavus* isolates produced aflatoxin compared to 9% from the non-treated field. All aflatoxigenic isolates produced only aflatoxins B1 and B2. A subset of *A. flavus* isolates were selected for genotyping. From these, isolates that failed to produce aflatoxin in culture were tested by polymerase chain reaction (PCR) to determine the presence of the aflC gene. From the Aflaguard-treated fields, 20% did not yield aflC PCR products (aflC -), thus were designated as Aflaguard-like. In contrast 8% of the isolates from the non-treated field were Aflaguard-like. The AF36 strain contains a mutation in AflC at nucleotide position 951. About 63% of the non-toxigenic strains from both AF36 treated and untreated fields from Texas yielded an aflC PCR product. DNA sequence analysis indicated that 56% of AF36-treated isolates contain the AF36 mutation, indicating that about 35% of the total non-aflatoxin-producing isolates were AF36-like. No AF36-like sequences were identified in the isolates obtained from the non-treated fields in Texas (Figure 1).

**Figure 1.** Aflatoxin-producing and non-aflatoxin-producing colonies and isolates in AF36-treated maize

**Activity 2: Testing Cobalt Chloride humidity sensor strips**

i) Description: Testing a variety of cobalt chloride solutions to obtain a very tight color break (from blue to pink) at 65% relative humidity (RH).
ii) Location: West Lafayette, USA
iii) Collaborators[6]: Charles Woloshuk and Sharon Kinyungu (Purdue)
iv) Achievements: The research team worked on adopting work from the US Patent (no. 2,627,505); Relative Humidity Indicator; M. E. Goodwin and E. A. Simpson 1953. This patent describes methods to achieve a narrow color break by adding salts such as sodium acetate and zinc chloride to the cobalt chloride solution used to make the humidity strips. The team also tested a variety of strip material to treat with the dye. Although we were able to

[6] Provide institutional affiliation and country.

achieve the targeted color break near 65% RH, we found that in the test chamber the strip material absorbed moisture over of time. Tests were conducted using maize and various salt solutions to obtain the targeted relative humidity. The hygrometer test was included in the study. The absorption of moisture implies that leaving the humidity indicator strip in the chamber longer than the prescribed time causes the strip to indicate a higher moisture than the actual value. The Dry Card ™ developed by the USAID/Horticulture Innovation Lab reported similar results. More work needs to be done to determine specific tie parameters to keep the stripes in the test chamber.

**Activity 3: Estimating demand for low cost moisture detection devices**

i. Description: Measuring the demand for the Hygrometer and DryCard
ii. Location: Kakamega, Kenya
iii. Collaborators[7]: Jacob Ricker-Gilbert, Jonathan Bauchet, Hira Channa (Purdue) and Hugo De Groote (CIMMYT, Kenya)
iv. Achievements:
v. Presentations and Publications:
    - Channa, H., J. Ricker-Gilbert, H. De Groote, J. Bauchet, and Paswel Marenya. 2018. Willingness to pay for a new farm technology given risk preferences. "Selected Paper at the IAAE Triennial Conference Vancouver, BC, Canada. July 28 to August 2, 2018.
    - Channa, H., J. Ricker-Gilbert, C.P. Woloshuk. 2018. "Scaling up low-cost moisture meters to improve income, food safety and health." Presentation made at the Scaling- Up Agricultural Innovations to Reach Millions Conference. Purdue University. West Lafayette, IN. USA., September 25-27, 2018.
    - Prieto, S., J. Bauchet, and J. Ricker-Gilbert. 2018. "Do improved drying and storage practices reduce aflatoxin contamination in stored maize? Experimental evidence from smallholders in southern Senegal." Organized Symposium at the IAAE Triennial Conference Vancouver, BC, Canada. July 28 to August 2, 2018.

This study was conducted in Kenya to measure the demand for Hygrometer and DryCard, two technologies from FPL and Horticulture Innovation Lab, respectively, for measuring moisture content in grains. The chronic presence of aflatoxins (dangerous toxins produced by the *Aspergillus* family of fungi) in maize is a major public health issue in Sub-Saharan-Africa. Fungal growth and aflatoxins production can be reduced by drying maize to 14% moisture content or below before storage. Most farmers do not have access to moisture meters, but several low-cost devices are now becoming available. Our main goals are (i) to estimate the demand for two low-cost maize moisture measurement devices among smallholder farmers and small-scale traders in Western Kenya, and (ii) to measure the impact of risk aversion on willingness to pay for the devices. We use experimental auctions with a Random Binary Choice mechanism, and we randomly vary the bidding order (low-to-high price or high-to-low price). We find that 60% of participants are willing to pay more than the estimated retail cost (USD 0.50 USD and 1.90 USD) for at least one of the devices, suggesting a potential high demand and opportunity for scaling up these technologies. More risk-averse farmers reported a higher WTP for the devices. Farmers, but not traders, are also sensitive to the bidding order with a difference of 33 % between bids elicited when the starting price was high and went lower, as compared to when the starting price was low and went higher. Figure 2 shows the demand curve for the hygrometer. It involves plotting out percent of population purchasing on y axis and the price on

[7] Provide institutional affiliation and country.

the x axis. The dotted lines display mean willingness to pay for farmers (USD 1.30) and traders (USD 1.20). This is above the wholesale price of USD 0.90. Figure 3 shows the potential profit for a retailer of the hygrometer. Assuming constant cost of USD 0.90 per hygrometer, estimated profit is calculated by multiplying the proportion of population likely to buy at each price with the margin at each price. Profit for hygrometer can be maximized by selling at $ 1.90 to 25% of the population. Figure 4 shows the comparison of the hygrometer to other moisture meters on the market. The hygrometer compares favorably in terms of cost and accuracy to the cheaper DryCard and the more expensive GrainMate and other more expensive devices.

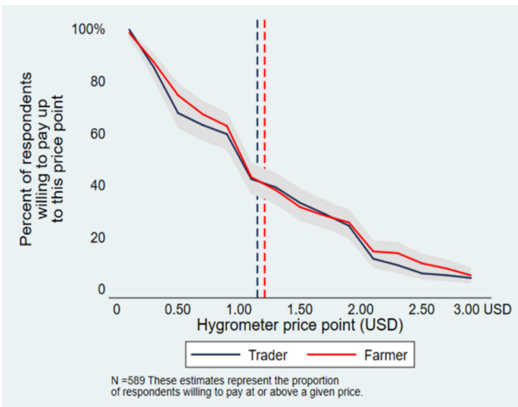



**Figure 2**. Demand for Hygrometers

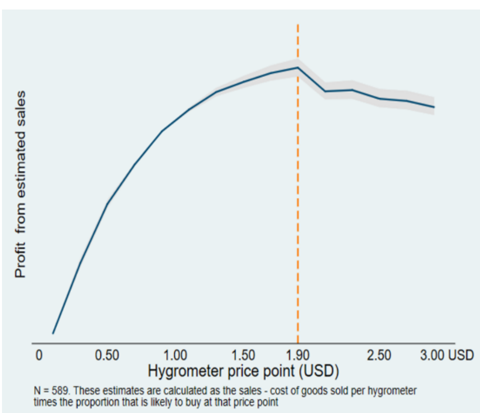



Figure 3. Potential profit for a retailer of the hygrometer

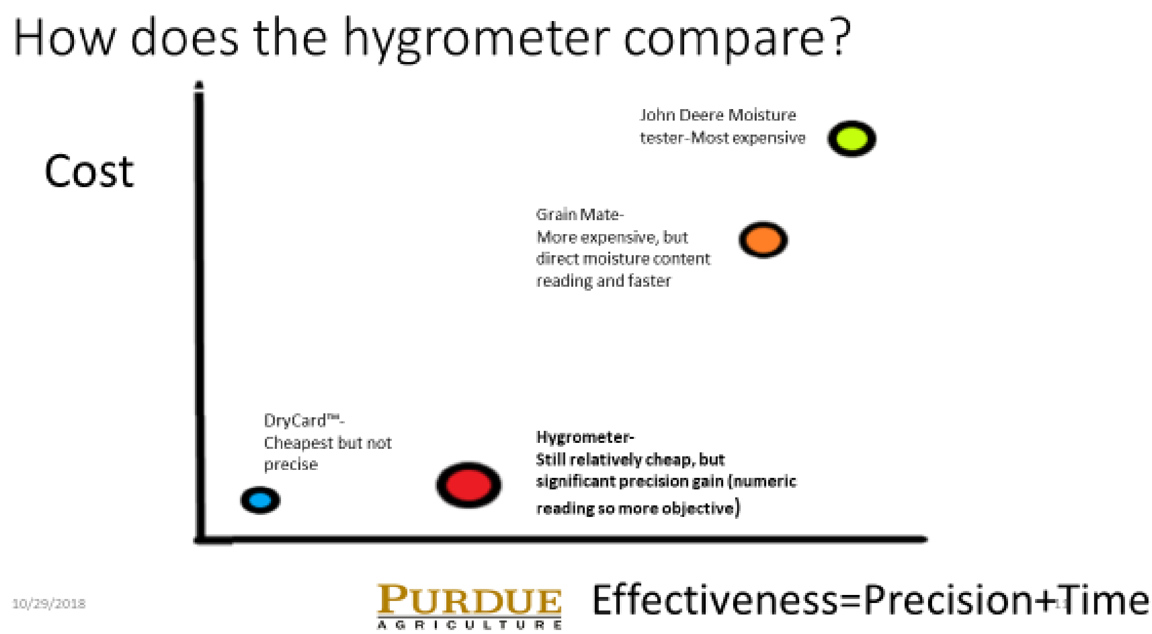



**Figure 4**. Comparison of hygrometer to other moisture meters on market

**Next steps**

- Make hygrometer device available for purchase from multiple manufacturers. If a bulk purchase is made directly from the manufacturer, the per-unit price of the hygrometer can be lowered below $0.90.
- Plan to use the input supply chain for the Purdue Improved Crop Storage Bags in various countries (currently under way in Kenya, Bell Industries, and Senegal, SEDAB).
- In Kenya, Bell Industries will look into getting permission to classify each commodity as an agricultural input in order to gain import tax exemption.
- Train extension workers on the usage of the product in the areas where we are piloting the product.
- Recognize that extension and public investments are needed to promote this new technology that offers public goods of improved food safety and health.

**<u>Activity 4: Study of the economics of roadside drying</u>**

i) Description: Estimating the economics of roadside drying
ii) Location: Western Kenya
iii) Collaborators[8]: Hugo De Groote and Benard Munyua, CIMMYT, Kenya
iv) Achievements:

Maize drying is a challenge for farmers and commercial actors in humid tropics that often results in quality loss and health problems from storing wet grain. There have been no economic analyses of dryers in the region. The objectives of this study were to calculate the cost of open-air maize drying, per bag and per % point of moisture reduced and to use the determined cost as a baseline to compare economic performance of solar and other dryers. The team interviewed 125 commercial maize actors in the major maize-growing areas of Kenya. They measured the moisture levels before, during, after drying to calculate the cost elements of open air drying (labor, equipment, etc.). They created cost calculations

[8] Provide institutional affiliation and country.

per bag and per point of moisture reduced during the drying season of July to January for maize in western Kenya.

Results suggest that open air maize drying takes two days to reduce moisture content from 17.8% to 12.5%. Most operators interviewed were maize traders and 58% used moisturemeters. The cost to dry maize was KSh 159.2 (1.6USD) per dry 90kg bag and the benefit from drying was KSh 37.9 (0.40 USD) per 90 kg bag of maize. These results suggests that open air maize drying is a very low margin business in Kenya. Operators make more money from transportation than drying of maize. Although drying is a necessary step in the supply chain, it is not profitable business (Table 1).

**Table 1.** Cost calculations for roadside drying in Kenya

| B/C | Elements | Value |
|---|---|---|
| Costs | Fixed costs per month (KSh/month) | 17,212 |
| | Number of bags dried per month | 859 |
| | Fixed costs per bag dried (KSh/bag) | 20 |
| | Labor cost (KSh/bag/day) | 52 |
| | Number of days to dry one bag | 2.7 |
| | Total labor cost (KSh/bag dried) | 139 |
| | Total cost per dried bag (KSh/bag) | 159 |
| Benefit | Moisture loss in percentage | 5 |
| | Price increase drying (KSh/bag) | 197 |
| Profit | Profit on drying (KSh/bag) | 38 |
| | Benefit/cost of drying | 1.2 |
| | Cost per point of moisture lost | 31 |
| | Profit on transport to market | 289 |

B/C- benefit/cost

**<u>Activity 5: Testing Solar Pico CrOp Dryer (POD), a low-cost on-farm solar grain dryer for small holder farmers</u>**

i. Description: on-station and on-farm testing of the improved version of the Solar Pico CrOp Dryer (POD 2.0)
ii. Location: Kenya
iii. Collaborators[9]: Arvind Raman and Richard Stroshine (Purdue), Patrick Ketiem (KALRO, Kenya)
iv. Achievements: Socio-economic research has shown a market need among African smallholder farmers for on-farm photovoltaic-powered grain dryers that cost less than $100, that can be disassembled and transported on the back of a motorcycle, and that can dry up to 90 kg 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 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

[9] Provide institutional affiliation and country.

more affordable and are in the same price range as 10W panels only a few years ago. With this capacity, it becomes possible to consider powering mechanical devices such as small capacity grain dryers and small refrigerators with Solar Pico Systems.

v. Presentations and Publications: Chen, M., Stroshine, R.L., Raman, A., and Ketiem, P. 2018. Pico Solar Crop Dryer (POD) for Farm Level Grain Drying by Small Holder Farmers in Africa. Paper 2018-01427 presented at the ASABE annual meeting, Detroit, MI, July 29 – August 1, 2018.

**Activity 5.1: Evaluation of the performance of the Solar Pico Crop Dryer (POD) in Kenya**

Based on the performance tests of the modified POD conducted in September 2017, the project team determined that it was ready for testing in Kenya, if trays [78 cm x 51 cm x 10 cm deep (31 inches x 20 inches x 4 inches deep)] and other components could be obtained. Five trays are needed for 100kg capacity of grain and each costing approximately $5 were purchased from China. The slots in the sides of five trays were sealed using flashing tape and pieces of wood lath were used to hold the plastic against the sides of the tray. The lath was 38 mm (1.5 in) wide and 6.35 mm (0.25 in) thick, with lengths varying between 25 cm (10 in.) and 93 cm (36.5 in). The thinner lath permitted 2 inch binder clips to be used to hold the lath in place. The fans were enclosed in a wooden frame and spring clamps were used to hold the lath and plastic to the top and sides of the fan because the binder clips would not work when thicker plastic must be attached to thicker pieces of wood such as those on the fan frame. An indoor test conducted using re-wetted maize showed that the trays performed well (Figure 5).

The components of the dryer were shipped to Kenya, assembled by the PI at KALRO (Dr. Patrick Ketiem), and tested on-station. Figure 6 shows the moisture content of the maize in the drying tests conducted. The test started at 8 am on the 15th of May and ended at 5pm. It was resumed at 8 am on the 16th and was ended at 2 pm. Drying was more rapid during the first day when the average moisture content of samples taken from the trays dropped from 21 % to 16.3 %. It appears as though the maize moisture content increased slightly overnight. This may have been caused by sampling variations. However, it is possible that the maize absorbed some moisture from the humid air. At the end of the second day of drying, the final average moisture content of the maize was 14.7%. Examination of the weather data revealed that the average air temperature was 18.5°C on May 15th and 17.5°C on May 16th. For both days the average wet bulb temperature was 15°C. However, there was 31.7 mm of rainfall on the 16th, which made drying conditions less than ideal. The Equilibrium Moisture Content (EMC) of the maize for the given wet bulb and dry bulb temperatures, calculated using the Chung Equation, was 14.4% on May 15th and 16.0% on May 16th. Apparently the solar radiation heated the air enough to increase its capacity to absorb water vapor from the maize and thereby reduce its moisture.

In order to reduce the size and weight of the fan frame, a new version of the POD was developed for tests conducted during the summer and fall of 2018. This new frame was lighter in weight and the thinner metal allowed the two inch binder clips to be used to seal the plastic and lath to the frame. Compared to previous versions, it was easier to tightly seal the plastic around the frame.

**Activity 5.2: Performance Testing of the Solar Pico Crop Dryer (POD) at Purdue University**

During June and early July of 2018, an aluminum frame was constructed from a sheet of aluminum and aluminum angle that could replace the wooden frame. Figure 1 shows pictures of the modified POD. Three tests were conducted with this POD at Purdue University during the summer of 2018. The first test was in July, the second in August, and the third in September. The July and August tests used 90 kg of maize rewetted to approximately 21% MC. Re-wetting involved adding the appropriate weight of water calculated to bring the dry sample to about 21%. After the water was added, the maize was mixed with a barrel roller for 8 to 15 hours. The maize for the September test was obtained from the Agronomy Center for Research and Extension (ACRE). Ears of maize were harvested by hand from a field and shelled at the Indiana Maize and Soybean Innovation Center located at ACRE. The sheller was driven by an electric motor and it was equipped with rubber rollers. The wet maize (30% MC) was divided into two approximately equal portions. One portion (139 kg) was dried on a tarp in a manner similar to that used in many parts of Africa, while the other portion (142 kg) was dried in the POD.

**Figure 5.** Picosolar crOp Dryer (POD) with aluminum fan frame tested during the summer of 2018. Upper picture shows the maize in the trays with the fan frame positioned along the side of the trays. The lower picture shows the POD trays with the plastic sheet in place fans running, and a 30 Watt solar panel.

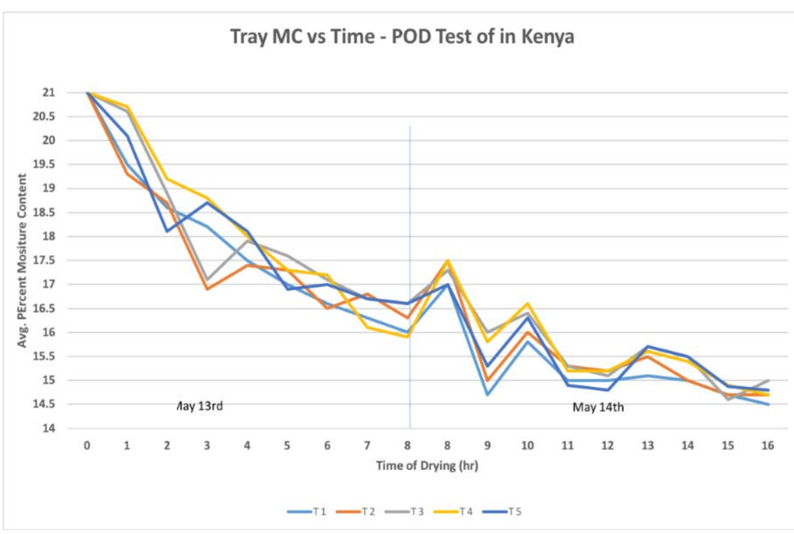



**Figure 6**. Moisture content of maize samples taken from the five drying trays during a drying test conducted in Kenya on May 15 and 16, 2018

Results of the three drying tests are summarized in Table 2. The drying rates were similar (range: 0.62 and 0.78 points of moisture per hour). The rates were higher, (approximately 1.0 point per hour), when the maize moisture content was above 16% and slower (approximately 0.25 percentage points per hour) when the maize was dried from 16% to 13%. Data logging (HOBO) sensors were placed at the fan inlet (sensor 1), on the top surface of the maize in the middle tray near the fans (sensor 2), on the top of the maize in the first tray which is furthest left in Figure 1 (upper picture) (sensor 3), and beneath tray 1 (sensor 4). This allowed measurement of the increase in air temperature that resulted from solar heating of the air. Exhaust air temperature and relative humidity were also monitored. Solar heating increased the air temperature by as much as 20ºF (see Table 2). Heating was greatest during the middle of the day (13:00 to 16:00) when solar radiation was striking the plastic near to perpendicular. The dryer was oriented with the long axis in the east and west direction, Therefore, in the morning (9 or 10 am) or late in the afternoon (18:00 to 19:00) the temperature increase was only a few degrees. The heating was usually lowest in the evening when the sun was lower in the sky and less radiation was striking the east end (Tray 1). Temperatures were also determined by outdoor thermometers, with the outdoor sensor placed on the surface of the maize in trays 1 and 5. These sensors indicated that late in the afternoon there was more heating of the air in tray 5, where the sun was more directly striking the plastic, compared to tray 1.

**Table 2.** Summary of POD drying tests conducted during the summer of 2018.

| Test Date | Weight Dried (kg) | Starting Moisture (pct) | Ending Moisture (pct) | Time of Drying (hr) | Avg. Drying Rate (pts/hr) | Increase in Air Temp in Tray 1 (°F) | Increase in RH below Tray 1, (%) |
|---|---|---|---|---|---|---|---|
| 07/18 | 90 | 21.2 | 12.2 | 11.6 | 0.776 | 12 to 19 | 2 to 20 |
| 08/09 | 90 | 21.0 | 13.4 | 12.25 | 0.620 | - 3 to 20 | - 4 to 31 |
| 09/12 | 110 | 30.1 | 13.3 | 24.5 | 0.686 | 1 to 11 | 13 to 45 |

The column “Increase in air temperature” is the difference between the temperature on the surface of the maize in tray 1 and the temperature of the air entering the fan inlet. Similarly, the increase in relative humidity (RH) is the difference between the RH of the air exiting below tray 1 and the RH of the air at the fan inlet.

Figure 7 is a plot of the moisture contents of samples taken from each of the 5 trays during the test with newly harvested maize at 30% MC. It was started on September 12th. The results for the tarp drying are also shown in Figure 3. The average final MC of samples taken from the 5 POD drying trays was 13.3%, while the final MC of the samples taken from the tarp was 13.5%. Drying time for the POD was 24.5 hours. The tarp drying time was also longer than the POD drying time in the test conducted with newly harvested maize in September of 2017 as reported in the 2017 annual report.

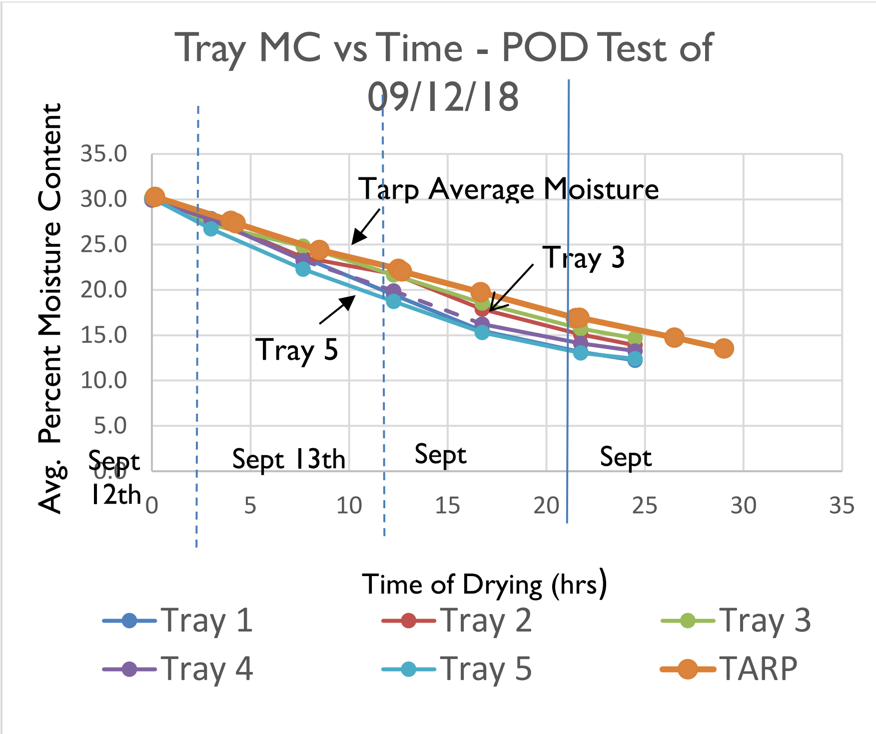



**Figure 7.** Moisture Contents of samples taken from the tarp and from the five drying trays for the POD test conducted at Purdue University.

One improvement that could be made in the POD is achieving a more uniform moisture among the trays. Figure 3 reveals that at the end of drying there was a difference in MC among the trays. Throughout most of the drying period, trays 1, 4 and 5 were lower in moisture than trays 2 and 3. At the end of drying the MC of the maize in tray 3 was 2.4% greater than the MC of the maize in tray 1 and 2.2% greater than the MC of maize in tray 5. In the tests conducted in July and August the maize in tray 3 also had a higher MC but only by about 1%. Examination of the sensor 2 temperatures revealed that the temperature on the surface of the maize in tray 3 was close to the ambient air temperature and sometimes slightly below ambient temperature, with the greater differences occurring in the morning (9:00 to 13:00) or evening (16:00 to 18:00). For the tests conducted in August, sensor 2 temperatures were 4°F to 7°F above ambient and in July they were 4°F to 10°F above ambient. There are several possible explanations. First, the angle of the sun relative to the position of the POD may have decreased the amount of solar heating achieved in the center of the POD where the plastic "bubble" was larger (Figure 7). In the September test, the initial moisture was much higher (30% versus 21%) and there may have been evaporative cooling occurring on tray 3. Also the higher initial moisture means more points of moisture were removed and this may have magnified differences. Factors affecting moisture spread will be investigated in the future.

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

**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 (Purdue University) & Mario Ferruzzi (North Carolina State University; Violet Mugalavai & Augostino Onkware (University of Eldoret, Kenya); Cheikh N'Diaye, Djibril Traore, Fallou Sarr (ITA, Senegal); John Taylor & Gyebi Duodu (University of Pretoria); Hugo DeGroote (CIMMYT, Kenya)

iv) Publications:

De Groote, H., S. W. Kariuki, D. Traore, J. R. Taylor, M. G. Ferruzzi, and B. R. Hamaker. 2018. Measuring consumers' interest in instant fortified pearl millet products: A field experiment in Touba, Senegal. Journal of the Science of Food and Agriculture 98 (6): 2320-2331. doi: 10.1002/jsfa.8722.

v) Achievements: Described under each activity conducted

**KENYA**

**Activity 1: Mapping exercise for qualitative and semi-quantitative descriptive analysis of commercial products to help optimize FPL product formulations for Kenyan market**

The FPL team (Mugalavai, Ferruzzi, DeGroote, and John Lubaale, University of Pretoria graduate student) convened in Eldoret in February of 2018 to conduct a mapping exercise involving qualitative and semi-quantitative descriptive analysis for commercial and FPL-developed products. The goals of the study were to understand the key attributes in commercial products and to determine how FPL products can be further differentiated to fit within the commercial space in the Kenyan market. A secondary objective was to determine which of the FPL product formulations would be most closely aligned with commercial products in order to define priority products for further consumer and market-testing studies. Eight commercial non-instant composite flours were purchased from local markets and four FPL products formulations were selected for this analysis. The products were derived from various grains sources but were selected based on primary composition of sorghum and maize. Commercial products were also "naturally" fortified with nutrient-rich plants (such as amaranth and orange flesh sweet potato), although nutritional information was not available on the package. FPL products were instant composites made from various proportions of maize and sorghum with set proportions of amaranth, orange fleshed sweet potato, and baobab fruit powder designed to deliver 25% Daily Value (DV) for provitamin A carotenoids and iron. Key product attributes were defined by four tasters and qualitative descriptive analysis.

The principal component analysis of attributes of FPL instant and commercial non-instant flours are presented in Figure 8. Results from this qualitative/semi-quantitative exercise suggest that FPL instant products were very similar in product characteristics to those non-instant fortified composite flour products present in market in Kenya. Considering the combined properties of instant and higher level of nutritional standardization, the results suggest FPL products closely align with commercial ones and have the added advantage of being high quality and instant. Optimization for flavor and color parameters may offer further opportunities to distinguish FPL products on the market. Costing and consumer/market testing of two formulas based on maize:sorghum blends is anticipated in 2019 in anticipation of commercialization of final product concepts.

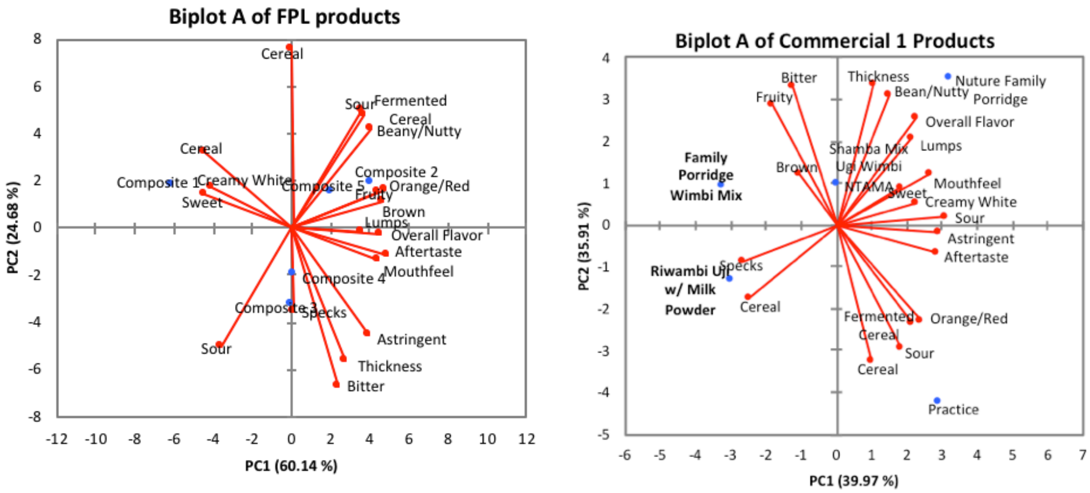



**Figure 8.** Biplots A of the principal component analysis for FPL product concepts and commercial products in Kenya

The left panel of Figure 8 with the Principal Components (PC) 1, 2, and 3 (not shown) explained 96% of the variance between the FPL products. PC1 separates Composite 5 and Composite 2 (both of which are characterized as having lumps, being brown, orange-red, and having fruity, beany/nutty, fermented cereal, and sour characters) from Composite 1 (characterized as being creamy white and having sweet and cereal characters). The right Panel with Principal Components (PC) 1, 2, and 3 (not shown) explained 90% of the variance between the commercial products. PC1 separates Practice (characterized as having a cereal, fermented cereal, and sour aroma, as well as being orange/red, astringent, and with an aftertaste), and Nuture Family porridge (characterized as being thick, beany/nutty, lumpy sweet, creamy white, sour, and with an overall flavor) from Family Porridge Wimbi Mix (characterized as brown, fruity, and bitter) and Riwambi Uji with Malt Powder (characterized as having a cereal flavor and specks).

**<u>Activity 2: Product concept development and certification</u>**

Five variations of extruded instant cereal products, developed, and processed at the University of Eldoret's Food Processing and Training Incubation Center (FPTIC), met the standards set by the national certifying body, Kenya Bureau of Standards (KEBS). FPTIC was given a permit to use the standardization mark and a license to officially start production for one year, starting 2018/5/14 to 2019/5/13. Figure 9 shows the certificate and product labeling panel.


**Figure 9.** Kenya Bureau of Standards certificate and sample of the certified FPL Product Concept

**SENEGAL**

**Activity 3: Strengthening rural processing with fortified instant millet processing in Senegal.**

Food processing incubation activities in Senegal led by Institut de Technologie Alimentaire (ITA) in partnership with a local processor, Mme. Astou Gaye Mbacke of Touba Darou Salam Processing Unit, focused on developing formulations and improving extrusion capability. The goal is to create a "Hub and Spoke" Innovation Center model for adoption of new food and nutrition technologies for scale-up in Senegal and the region.

ITA and FPL worked with Mme. Mbacke to remodel Touba Darou Salam's extrusion processing facility to help meet the standards for processing of safe and hygienic nutrient-fortified instant millet flours to supply food aid organizations. Dialogue progressed with government of Senegal officials through a solicited Concept Note to collaborate with certain departments and the World Food Programme to expand the extrusion processing capability of Touba Darou Salam Processing Unit to produce fortified instant flours and to scale-up the model to other regions of Senegal.

**Activity 4. Product development/optimization and sensory tests on product formulations for the Senegalese market.**

Activities were held on June 15-16 and August 7-10, 2018 to narrow final formulations for a consumer market study to be held in the fifth year of the project. The ITA team conducted two different descriptive tests as described below:

First test:

The group was composed of C. Ndiaye and D. Traore of ITA, and J. Taylor and M. Ferruzzi. A descriptive analysis on nine products developed by ITA (Table 3) was conducted using whole grain extruded instant millet flour plus natural and premix fortificants. Four product formulations were selected based on some quality attributes that the whole group discussed and approved. Target nutritional fortification was 25% Recommended Daily Allowance (RDA) of pro-vitamin A and iron.

**Table 3.** Different product formulations in the first sensory test. The highlighted columns in red are the selected products with photos shown.

| | Product 1 | Product 2 | Product 3 | Product 4 | Product 6 | Product 7 | Product 8 | Product 9 |
|---|---|---|---|---|---|---|---|---|
| | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) |
| Whole millet | 69,9 | 64,9 | 64,9 | 85,4 | 75,375 | 84,8 | 64,9 | 79,8 |
| Carrot powder | 19,9 | 14,9 | 14,9 | 9,4 | 9,4 | | | |
| Baobab powder | 10 | 10 | 15 | 5 | 10 | 10 | 10 | 10 |
| Papaya powder | | | 5 | | 5 | | | |
| Mango powder | | 5 | | | | | 5 | |
| Moringa powder | | | | | | | 5 | |
| Hibiscus powder | | | | | | 5 | 14,9 | 10 |
| Premix | | | | 0,05 | 0,025 | | | |
| Salt | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 |
| Citric Acid | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 |

Second test: ITA team (F. Sarr, C. Ndiaye, D. Traore, S. Sow, M. Samb, Y. Ndiaye, L. Mendy, A. Diouf, and 8 students) further worked on the optimizing the four selected product formulations shown in Table 4.

**Table 4:** Selected products after another descriptive analysis on the four previous and optimized formulated products.

| | Product 3 | Product 3 opt 1 | Product 3 opt 2 | Product 2 | Product 2 opt | Product 6 | Product 6 opt | Product 9 | Produ ct 9 opt |
|---|---|---|---|---|---|---|---|---|---|
| | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) |
| Whole millet | 64.9 | 69.9 | 74.9 | 64.9 | 72,4 | 75,4 | 75,4 | 79.8 | 84.9 |
| Carrot powder | 14,9 | 14,9 | 14,9 | 14,9 | 14,9 | 9,4 | 11,9 | | |
| Baobab powder | 15 | 10 | 5 | 10 | 5 | 10 | 5 | 10 | 10 |
| Papaya powder | 5 | 5 | 5 | | | 5 | 7,5 | | |
| Mango powder | | | | 5 | 5 | | | | |
| Moringa powder | | | | **5** | 2,5 | | | | |
| Hibiscus powder | | | | | | | | 10 | 5 |
| Premix | | | | | | 0,025 | 0,025 | | |
| Salt | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 |
| Citric Acid | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 |




Product 2 opt, product 3 opt, product 6 opt, and product 9 opt represent the final optimized formulated products chosen during the second test.

## Activity 5: Phytate reduction in extruded blends of millet

Some of the nutrient-rich plant materials targeted for natural fortification have been found to contain anti-nutritional factors such as phytates. A study was conducted by an FPL student on the effect of baobab (*Adansonia digitata*) and moringa (*Moringa oleifera Lam*) on phytate reduction in extruded blends of millet.

Samples tested included:

(a) Extruded blend of millet + moringa, ratio of (90:10)
(b) Extruded blend of millet + baobab, ratio of (90:10)
(c) Extruded blend of millet + moringa + baobab, ratio of (80:10:10)

The results (Table 5) showed that extrusion processing significantly reduces phytate levels in the millet-moringa blend. The 90:10 extruded millet:moringa had the highest percent reduction in phytate and the lowest vitamin C reduction.

**Table 5.** Phytate reduction of millet-moringa blends

| Composition of the products | Water content | Protein | Lipid | Vitamin C | Phytate | Phytate reduction, % |
|---|---|---|---|---|---|---|
| Extruded millet + baobab (90:10) | 7.4 ± 0.1c | 9.5 ± 0.3c | 1.7 ± 0.2b | 7.5 ± 0.5c | 2861.5 ± 671.9c | 11.46 |
| Extruded millet + moringa (90:10) | 7.4 ± 0.3c | 11.3 ± 0.2b | 1.7 ± 0.3b | 2.1 ± 0.2d | 3149.7 ± 507.9c | 29.34 |
| Extruded millet + baobab + moringa (80:10:10) | 6.7 ± 0.01d | 11.2 ± 0.2b | 2.0 ± 0.2b | 12.0- ± 0.8b | 4267.8 ± 393.6ac | 9.16 |
| Dry blend of millet flour + baobab (90:10) | 8.7 ± 0.1ab | 10.6 ± 0.3b | 2.8 ± 0.1a | 27.5 ± 1.2a | 3231.9 ± 683.1ac | – |
| Dry blend of millet flour + moringa (90:10) | 8.9 ± 0.02a | 13.1 ± 0.4a | 3.1 ± 0.1a | 3.5 ± 0.4d | 4457.7 ± 530.9a | – |
| Dry blend of millet flour + baobab + moringa (80:10:10) | 8.7 ± 0.1b | 13.03 ± 0.7a | 3.2 ± 0.4a | 28.4 ± 0.1a | 4698.2 ± 509.3a | – |

**SOUTH AFRICA**
**University of Pretoria:**

**Activity 6: Effect of extrusion cooking on sensory characteristics of pearl millet porridge**

Although pearl millet remains popular in traditional communities in semi-arid regions of Africa, it has been displaced considerably by other cereals among more affluent consumers. This is in part due to the strong "mousy" flavor of its food products, which is partly a result of lipid rancidity that develops during storage of the flour. PhD student Isiguzoro Onyeoziri working with Profs Riëtte de Kock and J. Taylor found that extrusion cooking positively affects the flavor of porridges prepared from stored wholegrain and refined pearl millet flours. Negative flavor attributes such as soapy-, painty-, and chemical-aromas and bitterness are reduced and positive attributes like sweet-, wheaty-, and sweet corn-aroma are increased (Table 6). This shows that extrusion cooking not only instantizes flour, but also extends its shelf-life and improves the flavor of the porridge. Application of extrusion cooking to processing pearl millet can thus expand the market for this nutritious cereal, especially as a wholegrain cereal.

**Table 6:** Effect of extrusion cooking on the sensory attributes of porridges made from wholegrain and decorticated (refined) pearl millet flour before and after storage for 24 weeks at 25°C

| **Attributes** | **Wholegrain** | | | | **Decorticated** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Conventionally cooked porridge** | | **Extrusion cooked porridge** | | **Conventionally cooked porridge** | | **Extrusion cooked porridge** | |
| | **Wk 0** | **Wk 24** | **Wk 0** | **Wk 24** | **Wk 0** | **Wk 24** | **Wk 0** | **Wk24** |
| ***Negative attributes*** | | | | | | | | |
| Sour aroma | 0.5 bc | 1.6 a | 0.4 bc | 0.3 c | 0.9 bc | 0.9 b | 0.3 c | 0.5 bc |
| Chemical aroma | 0.3 b | 4.0 a | 0.0 b | 0.5 b | 0.6 b | 4.6 a | 0.3 b | 0.6 b |
| Soapy flavour | 0.4 c | 1.4 ab | 0.3 c | 0.3 c | 0.3 c | 2.1 a | 0.2 c | 0.6 bc |
| Painty flavour | 0.8 bc | 2.1 a | 1.4 abc | 1.7 ab | 0.5 c | 1.8 ab | 1.1 abc | 0.5 c |
| Chemical flavour | 0.9 b | 3.9 a | 0.7 b | 0.8 b | 0.5 b | 5.1 a | 0.3 b | 0.4 b |
| Bitterness | 1.7 ab | 3.6 a | 1.0 b | 1.4 b | 1.3 b | 2.7 ab | 1.2 b | 0.9 b |
| ***Positive attributes*** | | | | | | | | |
| Sweet aroma | 1.9 b | 1.3 b | 5.6 a | 5.1 a | 1.6 b | 0.9 b | 5.1 a | 5.2 a |
| Wheaty aroma | 3.0 abc | 1.6 c | 4.5 ab | 4.5 ab | 2.2 bc | 1.5 c | 4.4 ab | 5.6 a |
| Canned sweet corn aroma | 3.1 bc | 1.3 d | 5.0 a | 4.5 a | 2.0 cd | 1.4 d | 3.8 ab | 4.1 ab |

Values with different letters in a row are significantly different ($p < 0.05$), Red highlighting indicates significant negative effects, Green highlighting indicates significant positive effects.

**UNITED STATES**
**Purdue University:**
**Activity 7: The effect of extrusion processing of millet on starch digestibility**

Typically, extrusion processing of starchy foods causes rapid starch digestion that results in high glycemic response. However, a study conducted on extrusion of whole grain millet flour showed formation of type-1 lipid-amylose complexes that had lower digestion profiles than extruded decorticated millet flours (Figure 10). Because the project is studying the potential to use whole grain millet in processing of instant fortified flours in West Africa, this finding could be important in that such products would be low glycemic in addition to containing higher levels of iron and zinc (particularly using biofortified millet).

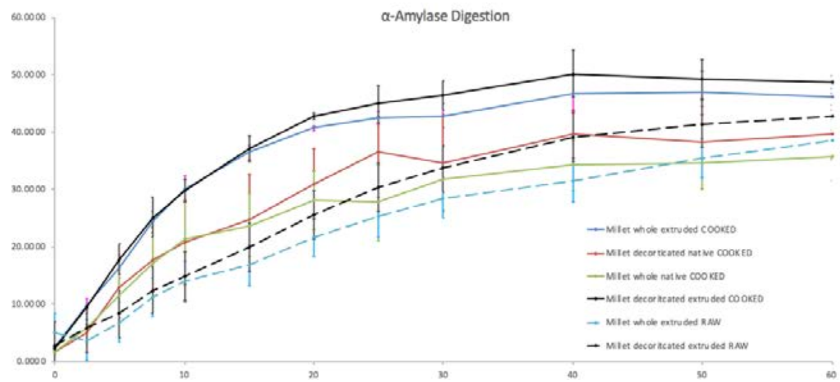



**Figure 10.** Starch digestion profiles of extruded millet flours, using α-amylase: showing that whole grain flours have lower digestion rates.

**Activity 8: Study to optimize extruder conditions that are applicable to African processors**

Effect of extrusion of sorghum flours at different moisture conditions on starch gelatinization and physicochemical properties have been reported. The lowest possible moisture conditions for complete gelatinization of starch during extrusion cooking is an important parameter for energy consumption of the extrusion process and the drying of extrudates that follows, prior to milling into instant flours. A study was conducted to determine optimum conditions for the extruder for use in resource-limited conditions. Such information is needed for entrepreneurs to optimize extrusion process for greater profit. The goal was to establish the optimum moisture content of extrudates to lower extrusion and drying energy cost and drying time. Sorghum was milled into grits and the moisture content adjusted to 27, 29, 31, 33 and 35% wet basis. After extrusion the extrudates were dried in a hot air oven at 50 degrees C, and then milled into flour. Degree of starch gelatinization was determined using differential scanning calorimetry, and pasting profiles were assessed using a Rapid ViscoAnalyzer, since good viscosity is needed in instant flours. The results of the study are discussed below:

- Extrusion at lower moisture conditions reduced the extruder screw speed and increased die temperatures.
- Extrusion at low moisture conditions led to greater shear as well as high temperatures leading to starch fragmentations and hence reduced viscosity.
- Extrusion between 27-35% moisture conditions completely gelatinized the starch, although the energy used was higher at lower moisture content due to greater friction caused by the feed.
- At lower moisture content, storage moduli was greater than loss moduli for the lower moisture extrudates, indicating the formation of more elastic extrudates.
- Ongoing studies to finish this project will: 1) measure power consumption during extrusion at different moisture conditions and drying time of extrudates, and 2) assess starch fragmentation using size exclusion chromatography.

**PROJECT 2**

i) Name: Nutritional studies
ii) Description: Screening of nutrient-rich plant materials for use in consumer-based food products and development of product concepts with Daily Value (DV) of 25% of in Senegal and Kenya.
iii) Collaborators[5]: Mario Ferruzzi - lead (NCSU); (Violet Mugalavai & Augostino Onkware (University of Eldoret, Kenya); Cheikh N'Diaye & Djibril Traore (ITA, Senegal); Johanita Kruger (formerly of University of Pretoria, South Africa).
iv) Achievements: Described under each activity conducted

**UNITED STATES**
**North Carolina State University and Purdue University**

**Activity 1: Translation of test formulation of cereal and nutrient-dense plant material blends to commercial versions of extruded products for Senegal and Kenya**

Progress has been made in the translation of test formulations of cereals and nutrient-dense plant material blends to commercial versions of extruded products for Senegal and Kenya. The formulations and products are based on pearl millet grain with nutrient dense plant powdered ingredients including solar dried carrot, baobob (*Adansonia digitata*) and moringa (*Moringa oleifera*) processed by extrusion to form a fully cooked composite flour according to parameters defined in Year 3 (blends of whole grain pearl millet with nutrient dense plant powdered ingredients including solar dried carrot, baobab, or moringa were adjusted to ~35% moisture prior to extrusion using a Technochem Mini-Extruder© with speed fixed at 900 rpm; final temperatures ranging between 105-121C) with a barrel diameter and L/D ratio 276 mm and 5:1, respectively).

In this reporting cycle, the compatibility of natural fortification strategies with a low-cost extrusion technology that is currently operating in Senegal and Kenya FPL projects were assessed. Blended products were formulated by combining whole grain (WG) millet (Senegalese Souna var.) with native African plant materials recognized as sources of micronutrients (iron and provitamin A carotenoids), including dried carrot (CRT)-15%), baobab-5% and moringa-5%. These levels were chosen for modest fortification targets of <20% of the DV as an initial step to assess alteration of physical properties and quality, as well as micronutrient recovery. Products were extruded (35% moisture; 900rpm; final average temp of 115C). Extruded products were assessed for quality (color, water absorption/solubility index, pasting properties and dynamic rheology) and nutritional value (provitamin A content, bioaccessibility and starch digestibility). Extrusion affected the color of the extrudates after carrot and baobab addition, showing greatest impact on browning index (156) and chroma (57.5) values, respectively. Water solubility and absorption indexes were significantly increased with carrot and baobab. However, baobab and moringa addition decreased product final viscosities. Rheological parameters including storage (G') and loss modulus (G'') were lower by addition of baobab and moringa. Starch digestibility was not altered by the formulation.

Provitamin A carotenoid stability through processing was significantly enhanced with the inclusion of baobab and moringa (60% in WG/CRT relative to 69% and 90% in WG/CRT/baobab and /moringa). Bioaccessibility of provitamin A carotenoids from these products was assessed by in vitro digestion. Primary provitamin A carotenoids, α-carotene (AC), and beta-carotene (BC), micellarization efficiency from dry blends of extruded millet and plant ingredients was comparable to composite extruded blends (Table 7). While no significant differences were

noted in bioaccessibility of carotenoids in dry blends, significant differences were observed in the extruded forms. Baobab addition showed the increased micellarization efficiency (12.8.6%) while moringa addition significantly reduced it (6.6%). This suggests that the extrusion process of blends of WG millet carrot, baobab, and moringa may alter the ability for the finished porridges to recover or release the carotenoids during the digestive process. The increase of micellarization efficiency (~1.2%) in extruded millet+carrot+baobab compared to extruded millet+carrot also suggests that an additional, albeit subtle effect, may be provided by baobab in relation to improving the bioavailability of carotenoids from blended cereal products.
Of the main formulations extruded millet+carrot+baobab blends had the highest levels of bioaccessibile provitamin A (~25% or 707 µg/100g porridge) (Figure 11), suggesting an enhancement of carotenoid bioavailability from these extruded composite cereal blends. These results show that production of naturally fortified millet blends can be achieved without compromising the product quality and recovery of provitamin A carotenoids.

**Table 7**. Micellarization efficiency of provitamin A carotenoids (AC, beta-carotene; BC, beta-carotene) in dry vs. extruded blends.

| **Provitamin A carotenoids** | **AC (%)** | **BC (%)** |
|---|---|---|
| Extruded Millet+Carrot | 5.37 ± 0.10b | 10.44 ± 0.18b |
| Extruded Millet+Carrot+Baobab | 6.55 ± 0.37a | 12.87 ± 0.76a |
| Extruded Millet+Carrot+Moringa | 2.94 ± 0.22c | 6.66 ± 0.22c |
| Dry blend of Extruded Millet + Carrot | 6.55 ± 0.38a | 11.93 ± 0.66ab |
| Dry blend of Extruded Millet + Carrot + Baobab | 6.98 ± 0.35a | 13.49 ± 0.78a |
| Dry blend of Extruded Millet + Carrot + Moringa | 5.55 ± 0.49a | 10.36 ± 0.36b |

PhD nutrition student Oluyimike Adetola working with Prof. John Taylor and Dr. Johanita Kruger has shown that inclusion of baobab fruit powder with pearl millet at a ratio of 15:100 can substantially increase the bioaccessibility (in vitro measure of bioavailability) of the iron from the pearl millet in the fortified porridge (Figure 11). Baobab fruit inclusion can be a sustainable strategy to improve mineral nutrition in the diets of at-risk communities in semi-arid regions of Africa, where baobab fruit is a popular dessert. The improvement in iron bioaccessiblity is probably due to the high levels of ascorbic acid and citric acid present in the baobab fruit powder. In fact, the improvement in iron bioaccessiblity is of the same magnitude as obtained with inclusion of ascorbic acid or citric acid at the same levels as present in the baobab. Interestingly, inclusion of moringa leaf powder has a negative effect on iron bioaccessibility despite the fact that moringa leaves are rich in iron. This probably is due to the presence in moringa of inhibitors of iron absorption, in particular its high content of calcium.

Building on this and related work, in order to better understand the potential for leveraging traditional plant-based ingredients like baobab fruit pulp and moringa leaves in local fortification efforts, a human stable isotope study is being undertaken in Kenya. This will assess iron bioavailability from whole grain maize porridges fortified with moringa fruit powder and baobab leaf powder, in comparison with conventional fortification of the maize porridge with mineral iron and ascorbic acid. Currently, the various food formulations are being analyzed and prepared at Pretoria. Ethical (institutional review board) approval has been obtained in Kenya and Pretoria, and is now being obtained from Purdue University.

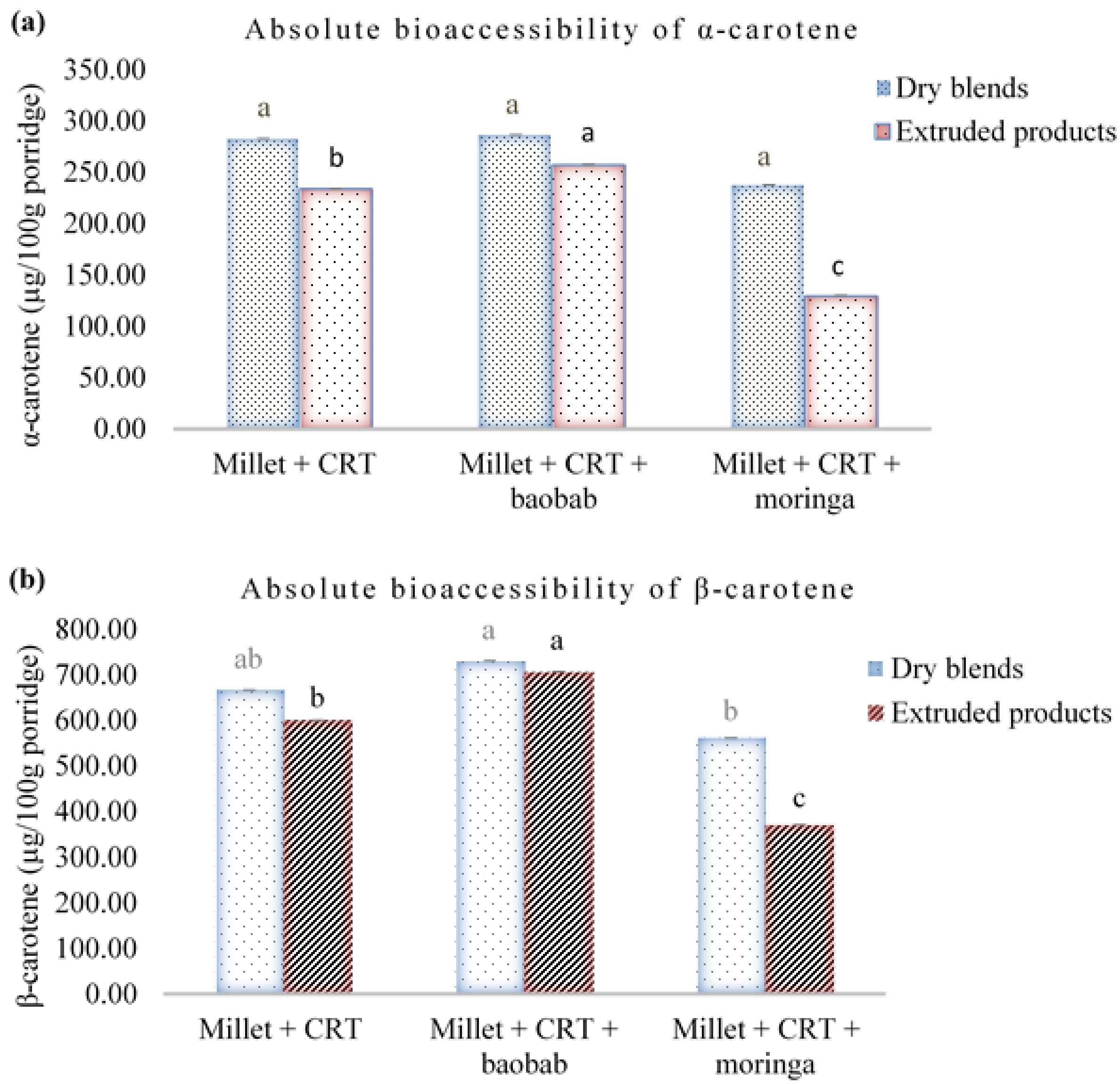



**Figure 11.** Amount of bioaccessible provitamin A carotenoids delivered from a 100 g serving of composite porridges produced by dry blending or through extrusion. Blue bars = % bioaccessible Fe, Red bars = amount of bioaccessible Fe (mg/100 g porridge, dry basis) Yellow blocks = change in % bioaccessible Fe, Red blocks = change in amount of bioaccessible Fe.

**Activity 2: Natural provitamin A fortification of sorghum using orange fleshed sweet potato**

Vitamin A deficiency affects a high proportion of children and women in sub-Saharan Africa. Cereals contain essentially no provitamin A. Hence, at-risk communities that have a low intake of animal-based foods need to consume complementary plant foods that are rich in provitamin A in order to meet their vitamin A requirements. One such plant food is orange-fleshed sweet potato (OFSP), which is rich in beta-carotene. A study was conducted by an MSc student, Rudu Maneya, working with Prof. Gyebi Duodu at the University of Pretoria to assess the use of orange fleshed sweet potato as a natural provitamin A fortificant for sorghum flour. The results showed that natural fortification of sorghum with OFSP to produce both conventionally cooked and extrusion cooked instant porridge can make a significant contribution to the Vitamin A requirements of at-risk groups (Table 8). For example, 100 g dry weight of porridge comprising 60% sorghum and 40% OFSP, equivalent to one large serving of 400 g porridge, can meet more than 10% of an adolescent's, adult female's, or lactating woman's vitamin A requirements. When the sorghum and OFSP are extrusion cooked, the level of provitamin A is reduced somewhat, by about 30%. This is presumably due to thermal destruction of the provitamin A.

**Table 8.** Contribution (%) of sorghum/orange fleshed sweet potato (OFSP) conventional cooked and extrusion cooked composite porridges to the recommended dietary allowance (RDA) for vitamin A for different groups.

| Sorghum:OFSP (w/w dry basis) | Vitamin A (µg RE/100 g porridge db) | Adolescents 10-18 years (RDA 600 µg RE/day) | Adults females (RDA 500 µg RE/day) | Lactating women (RDA 850 µg RE/day) |
|---|---|---|---|---|
| 100:0 conventional | 0.0[a] | | | |
| 100:0 extruded | 0.0[a] | | | |
| 90:10 conventional | 8.73[c] | 1.46[c] | 1.75[c] | 1.03[c] |
| 90:10 extruded | 6.38[bc] | 1.06[bc] | 1.28[bc] | 0.75[bc] |
| 60:40 conventional | 94.85[e] | 15.81[e] | 18.97[e] | 11.16[e] |
| 60:40 extruded | 65.61[d] | 10.91[e] | 13.13[f] | 7.70[f]± |

RE = retinol equivalent, Mean values in a column with different letters are significantly different ($p < 0.05$).

**<u>University of Pretoria, North Carolina State University, Purdue University:</u>**

**<u>Activity 3: Clinical Trial on hypothesized improvement of iron bioavailability</u>**

A human subject clinical trial will be done in February-April 2019 to evaluate whether natural fortification of instant pearl millet porridge products using moringa leaves (as an added source of iron) and baobab fruit pulp (as a source of ascorbic and other organic acids to act as mineral promoters) can effectively increase iron and zinc absorption when compared to conventional fortification using iron salts. The human subjects will be young women who are marginally deficient in iron. The study will involve assay of serum iron and zinc using stable (non-ionizing) mineral isotopes. The study is planned to be undertaken by Purdue, North Caroline State, and Pretoria, together with partners in Kenya. The Institutional Review Board application to use human research subjects has been submitted and approved in Kenya at the University of Eldoret and at the University of Pretoria, South Africa and is in process currently at Purdue University.

IV) Human and Institutional Capacity Development[10]

a) Short-term training

**Activity 1: Training of trainer, traders, and farmers in Kenya and Senegal**

i. Description: Training workshops for extension agents and farmer trainings on promising FPL technologies and drying/storage best practices.

ii. Location: Kolda, Senegal and Trans-Nzoia County, Kenya

iii. Collaborators: PIs from Purdue, ISRA, CIMMYT, and KALRO

iv. Achievements: Two day train-the-trainer workshops were conducted in Kolda, Senegal and Trans-Nzoia County, Kenya. Both workshops equipped trainers with best management practices for drying and storing grain, knowledge about aflatoxin contamination in grain, its health effects and prevention through best post-harvest management practices, and the demonstration and use of technologies developed under the project (determination of maize moisture by hygrometer method, PICS bag storage method, and the use of solar dryers).

| **Country of Training** | **Brief Purpose of Training** | **Who was Trained[11]** | **Number Trained[12]** | | |
|---|---|---|---|---|---|
| | | | **M** | **F** | **Total** |
| Kenya | Equip Extension agents and equipment providers with appropriate technologies and management methods | Agricultural Extension agents, farm technology and service providers, farmers | 26 | 21 | 47 |
| Kenya | Train people on proper post-harvest practices and FPL drying and storage technologies. | Farmers, traders, and ministry of agriculture staff | 900 | 700 | 1,600 |
| Senegal | Equip Extension agents and equipment providers with appropriate technologies and management methods | Agricultural Extension agents, farm technology and service providers, farmers | 16 | 2 | 18 |
| Senegal | Train people on proper post-harvest practices and FPL drying and storage technologies. | Farmers | | | 1,173 |

**Activity 2: Extension Activities in Kenya**

i. Description: Extension trainings and sensitization on promising technologies were conducted in Western, Kenya led by KALRO (Dr. Patrick Ketiem). The trainings were undertaken through organized county farmer training sessions, exhibition forums, annual training-of-trainers workshop, and Institutional policy manager's sensitization/engagements meetings. Five major maize growing counties of Western Kenya (Nandi, Trans-Nzoia, Uasin Gishu, Bungoma, and Nakuru) were covered, targeting farmers, agricultural extension staff, traders and other service providers in the agricultural sector within the specific counties. The technologies disseminated were: moisture detection device (hygrometer), solar dryers, and hermetic storage bags (PICS). The training was also used to sensitize farmers to adopt post-harvest practices, which

[10] 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.

[11] Such as farmers, government officials, women entrepreneurs

[12] Disaggregate by sex if known.

contributes to increased food security and household income. The training forum also provided opportunities to engage stakeholders on identification of challenges and opportunities in grain post-harvest management.

ii. Location: Western, Kenya

iii. Collaborators: PIs from Purdue, KALRO, and CIMMYT; Bell Industries staff

iv. Achievements: Overall, 1,600 farmers were trained and sensitized on the FPL technologies addressing post-harvest loss reduction. The number of men trained and sensitized under the project were slightly higher than for women. The majority of the people were trained through the inter-county organized sessions that took place in the five counties of western Kenya, followed by the FarmTech Expo event that took place in August 2018 at Naivasha. The forums are suitable channels to consider for future training and sensitization activities.

During the Inter-county training sessions, over 80% of the participants trained were farmers. In the train-the-trainers workshops held at Trans Nzoia County (Kenya's grain basket), agricultural extension staff were drawn from the five maize-growing counties of western Kenya (Figure 12). In the FarmTech Expo 2018 event, students from surrounding agricultural-based tertiary institutions, such as the Dairy Technical Institute (DTI), formed the majority of the participants. Engagement with institutional managers in the agricultural sector influencing the day-to-day operations is critical if scaling up of the technologies is to be achieved. During this reporting period, managers from at least six different institutions were engaged and sensitized on the project technologies. Managers from Kenya Cereal Enhancement Programme (KCEP) coordinating unit were the majority sensitized on incorporating FPL developed technologies to combat post-harvest losses. The KCEP programme targets to benefit more than 100,000 smallholder farmers whose livelihoods depend on maize and other cereals. Post-harvest management is one of the programme core activities.

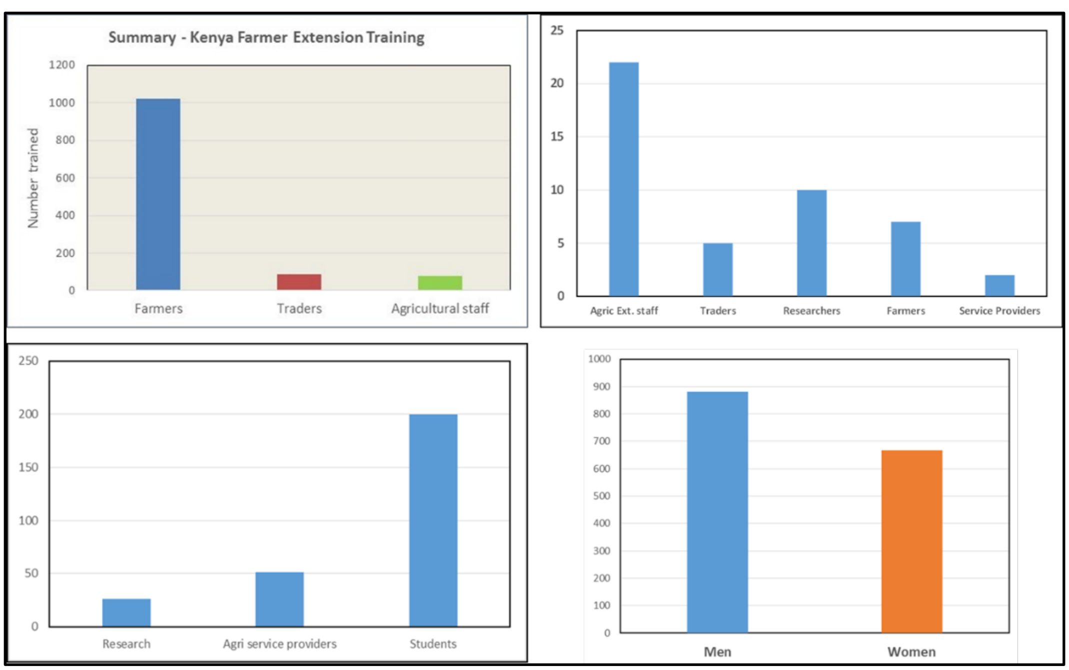



**Figure 12.** Summary of stakeholders trained during the Inter-County sessions segregated by stakeholder type, training session, and gender.

**Activity 3: Workshops for youth on food processing technologies**

i. Description: Training workshops were conducted for food processors by the University of Eldoret team.
ii. Location: Eldoret, Kenya
iii. Collaborators: University of Eldoret team
iv. Achievements:

| Country of Training | Brief Purpose of Training | Who was Trained[13] | Number Trained[14] M | F | Total |
|---|---|---|---|---|---|
| Kenya, University of Eldoret | Training in Cereal processing and natural fortification | Youth | 7 | 34 | 41 |
| Kenya, University of Eldoret | Cereal processing and natural fortification | Youth Incubatees | 3 | 7 | 10 |

**Activity 4: Conducted training workshops for food processors in Senegal**

i. Description: Training workshop on extrusion technology was conducted for food processors by FPL-ITA team in collaboration with USAID-ERA project.
ii. Location: Eldoret, Kenya
iii. Collaborators: FPL-ITA and the USAID-ERA project
iv. Achievements: Forty processors (12 males, 28 females) were trained (July 2-6) on extrusion processing though a collaboration between FPL-ITA and the USAID-ERA project (training activity funded by ERA). ERA-Senegal program has formed 50 active Economic Interest Group (GIE) including four platforms of processors: Dakar, Saint-Louis (north of Senegal), Diourbel (Touba area), and Ziguinchor (south of Senegal). The training was for the Diourbel region's food processors platform. Four representatives from each of the other 3 GIEs participated in the training conducted at Mme. Mbacke's Touba Darou Salam Processing Unit.

| Country of Training | Brief Purpose of Training | Who was Trained[15] | Number Trained[16] M | F | Total |
|---|---|---|---|---|---|
| Senegal, Touba | Training workshop on extrusion technology | Processors from Diourbel region's platform and representatives from the other 3 regional processor platforms | 12 | 28 | 40 |

[13] Such as farmers, government officials, women entrepreneurs
[14] Disaggregate by sex if known.
[15] Such as farmers, government officials, women entrepreneurs
[16] Disaggregate by sex if known.

**Activity 5: FPL PIs from Kenya attended the scale-up conference held at Purdue**

i. Description: FPL collaborators from Kenya attended the scale-up conference held at Purdue, September 25-27 with over 300 attendees from government, private sector, foundations, and civil society.
ii. Location: Purdue University, West Lafayette, IN.
iii. Collaborators: N/A
iv. Achievements: Drs. Violet Mugalavai (University of Eldoret) and Patrick Ketiem (KALRO) attended the 3-day Scale-Up conference held at Purdue University. FPL's promising technologies were displayed including the hygrometer, DEHYTRAY (a multipurpose solar dehydration tray), and instant fortified cereal flour formulations were presented. Dr. Mugalavai presented a poster on "Technology-Based Incubation Centre for Developing Affordable Nutritious Foods: Scaling up of Food Processing Training and Incubation Centre Technologies" (Appendix A). She also stay an extra week to attend the 3-day Whistler Center for Carbohydrate's short course geared towards individuals who want an in-depth review or refresher course on starch fundamentals.

b) Long –term training

| Name | Sex | University | Degree | Major | Program End Date[17] year) | Degree Granted [18] | Home Country |
|---|---|---|---|---|---|---|---|
| Rose Likoko | Female | University of Eldoret | MS | Food Science | 2019 | No | Kenya |
| Harriet N. Omutimba | Female | Pwani University | PhD | Social Ethics & Gender | 2019 | No | Kenya |
| Emmanuel Ayua | Male | Purdue University | PhD | Food Science | 2019 | No | Kenya |
| **Cheikh Ndiaye** | **Male** | **Purdue University** | **PhD** | **Food Science** | **2018** | **Yes** | **Kenya** |
| Sharon Wanjiru Kinyungu | Female | Purdue University | MS | Plant Pathology | 2019 | 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 Sci. & Nutrition | 2019 | No | Senegal |
| Abdourahmane Diop | Male | University of Thiès | MS | Agricultural Economics | 2017 | No | Senegal |
| **Adeoluwa Adetunji** | **Male** | **University of Pretoria** | **PhD** | **Food Science** | **2015** | **Yes** | **Nigeria** |
| **Nokuthula Vilakati** | **Female** | **University of Pretoria** | **PhD** | **Food Science** | **2016** | **Yes** | **South Africa** |
| Oluyimika Adeotola | Female | University of Pretoria | PhD | Nutrition | 2019 | No | Nigeria |
| Isiguzoro Onyeoziri | Male | University of Pretoria | PhD | Food Science | 2018 | No | Nigeria |
| Adeyemi | Male | University of | PhD | Food | 2017 | No | Nigeria |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Adeyanju | | Pretoria | | Science | | | |
| 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** | **Yes** | **Botswana** |
| **Tim Tubbs** | **Male** | **Purdue University** | **MS** | **Plant Science** | **2016** | **Yes** | **USA** |
| **Brett Lane** | **Male** | **Purdue University** | **MS** | **Plant Science** | **2016** | **Yes** | **USA** |
| **Stacy Prieto (McCoy)** | **Female** | **Purdue University** | **PhD** | **Agricultural Economics** | **2019** | **Yes** | **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** | **Agric. & Biological Engineering** | **2017** | **Yes** | **Nepal** |
| Hira Channa | Female | Purdue University | PhD | Agricultural Economics | 2019 | No | Pakistan |
| Amanda Fuller | Female | Purdue University | MS | Agricultural Economics | 2019 | No | USA |
| Mingyuan Chen | Female | Purdue University | MS | Agricultural & Biological Engineering | 2019 | No | China |
| Rudu Maneya | Female | University of Pretoria | MS | Food Science | 2019 | No | South Africa |

i) For students who have completed their degree and returned to their home country, indicate if they are employed in their field and the name of the employer if known.
Eight students have graduated from the program (6 male and 2 female/ 4 MS and 4 PhD). Six returned to their countries and 4 of them are known to be working. One was a US citizen and work for a non-profit organization in the US.

c) Institutional Development
i) Description: N/A
ii) Partners: N/A

V) Innovation Transfer and Scaling Partnerships[19]

a) **Expert assessment of the scalability of FPL generated innovations: hygrometer and "Hub and Spoke" food innovation system**

i) **Steps taken:** The FPL submitted two innovations for assessment by a team of scaling experts during the Scaling-Up Conference held at Purdue on September 25-27, 2018 Appendix B. The goal of the assessment was to provide feedback with regard to key strengths and weaknesses relative to readiness of the innovation for scale-up and to provide suggestions

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

for scalable pathways. Summary of the feedback obtained on the innovations is provided in Appendix C.

ii) **Partnerships made:** N/A

iii) **Technologies ready to scale**: hygrometer-based method for measuring moisture content of grains and "Hub and Spoke" food innovation system for disseminating of food processing and nutrition technologies and strengthening food processing businesses.

iv) **Technologies transferred:** N/A

v) **Technologies scaled**: N/A

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

i) **Steps taken**: FPL in partnership with PICS have worked to add a plastic jar to the hygrometer to make it a more standardized product compared to placing the device in a plastic bag containing a small amount of grain (50g) for testing (Figure 13). Dieudonne Baributsa (Purdue) has engaged PICS bags manufacturers on the possibility of producing a hygrometer product that can be sold through the PICS supply chain. Additionally, Global Good continues to work on refining and improving the hygrometer and hope to have a new prototype of the device ready for the market testing by the end of 2019


**Figure 13.** Standrdized product of hygrometer embedded in a plastic jar

ii) **Partnerships made**: working with PICS

iii) **Technologies ready to scale:** Improved product of hygrometer embedded in a plastic jar.

iv) **Technologies transferred:** N/A

v) **Technologies scaled:** N/A

c) **Commercialization of the DEHYTRAY**

i) **Steps taken:** JUA Technologies International LLC. (JTI), the start-up founded by Ileleji (FPL PI) is commercializing the two multipurpose solar dehydration devices successfully registered under two trademarks with the USPTO - the DEHYTRAY$^{TM}$, for the multipurpose solar drying tray and the DEHYTRAY$^{TM}$, for the multipurpose solar dryer and power generator. Improvements of the multipurpose dryer, DEHYTRAY$^{TM}$, has been made by redesigning a more efficient solar collector. The first version of the electronics control system that would enable the solar dryer to run automatically and efficiently with the new solar collector has been completed by JTI as part of efforts toward commercial production. Figure 14 shows that the peak temperature of the new collector design was about 20C higher than the old collector design, and 40C higher than the ambient. The goal is to transfer most of this heat gain from the collector to the drying chamber by using our electronic control system. JTI is pursuing grants from NSF and USDA SBIR programs to develop the DEHYMELEONTM toward commercialization.

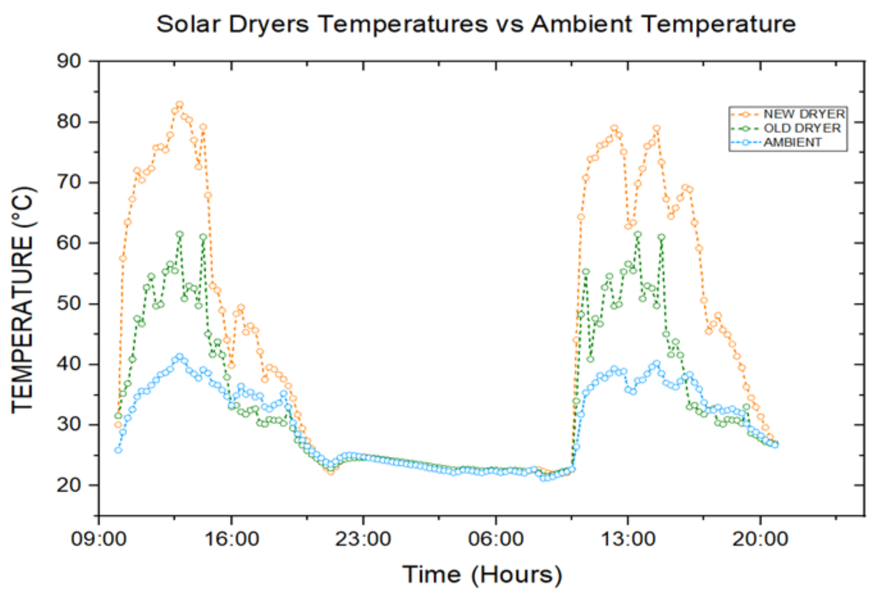



**Figure 14.** Comparison of temperature achieved by the new collector design (new dryer vs. old dryer).

ii) **Partnerships made:** Several potential partners that could play a role in commercializing the technologies in Senegal and Kenya were visited during the in-country trip to conduct train-the-trainer workshops. In Senegal, the team visited SEDAB (seed producer) and Madam Mbacke's facility (Purdue University Food Technology Processing Hub) in Touba. The DEHYTRAY$^{TM}$ and hygrometer was demonstrated for use in drying extruded instant mix at the former. In Kenya, the team visited Bell Industries, Trans-Nzoia Ministry of Agriculture, Kenya Cereal Enhancement Programme (KCEP), and KALRO in Nairobi, Kenya Industrial Estates (KIE), and Quipbank/TingA Project (serves 2,000 farmers with machinery services in Kenya).

iii) **Technologies ready to scale:** JTI has been engaged with an Indiana-based company to manufacture the DEHYTRAY$^{TM}$. JTI invested in product design for manufacturing, parts prototyping/testing, and injection mold manufacture. Injection molding technology is used to manufacture the DEHYTRAY$^{TM}$, using a polymer that would not easily degrade by ultra violet light and also one that is approved by the FDA for food contact. The DEHYTRAY™ comes in three parts, which can be intuitively and easily assembled within a minute. It weighs about 3.5 lb (1.6 kg) when assembled and could hold up to 20 lbs (9 kg) of maize (corn) per batch for drying stand-alone. Testing of the first shots (first manufactured units) has been taking place since June 2018 at Purdue and with various JTI partners (Fort Valley State University in Georgia, USDA-ARS Lab in Albany and at a farm in Brentwood, California, and briefly in Oregon). Three samples were provided to FPL project team in Senegal and Kenya for demonstration and brief testing. Initial reviews of the DEHYTRAY™ by various stakeholders and USAID Kenya Mission staff were quite positive. Figure 15 shows the DEHYTRAY™ being shown and tested in drying of extruded instant cereal mix at Madam Mbacke's processing facility in Touba, Senegal.

Results of various tests of the DEHYTRAY™ show that:

- The temperature within the tray increases to twice the ambient temperature in less than 30 minutes, thereby increasing crop drying rate.
- Drying rate of the DEHYTRAY™ exceeds ambient open sun-drying, especially in poor weather conditions.
- The handling of crops to be dried is a lot easier.
- The DEHYTRAY™ provides a better phytosanitary drying environment.

**Figure 15.** DEHYTRAY™ being demonstrated at Madam Mbacke's cereal processing facility in Touba, Senegal.

iv) **Technologies transferred**: In year 5, our local collaborators will pilot the DEHYTRAY™ in Kenya (KALRO) and in Senegal (ISRA). Various business models of technology access will be pursued by local cooperatives and SMEs.

v) **Technologies scaled:** DEHYTRAYTM will be manufactured to scale and made available for purchase online, as well as by special order of large shipments overseas. Orders can be made in thousands of units. The manufacturer, parts supplier, and order fulfillment facility are all within 2 to 30 minutes from each other, and about 1h and 30 min from Purdue University, West Lafayette campus. JTI long-term goal is to understand and manage product manufacturing in Indiana, after which manufacturing and distribution know-how would be easily transferred to other parts of the world. As product penetration grows in various countries, regional manufacturing would be eventually pursued to fulfill orders locally.

d) **Scaling-up of nutritious instant food products to help address malnutrition in Senegal**

i) **Steps taken:**

FPL's goal has been to develop cost-effective nutritious products that consumers want to eat, thus creating a market pull, especially at rural levels. The program has generated compelling data on this market-driven fortification strategy through Willingness-To-Pay

(WTP) and consumer acceptability studies. The fortified product prototypes (e.g. couscous, thin/thick porridges) target 25% of the recommended daily allowance (RDA) for shortfall micronutrients Vitamin A, Fe and Zn, using a combination of natural fortificants and vitamin-mineral premixes depending on cost. The government of Senegal has expressed interest in using the low-cost nutritious instant food formulations in government program to address malnutrition in the country. FPL and ITA have been working with a local processor, Mme. Astou Gaye Mbacke of Touba Darou Salam Processing Unit, to adopt the formulations to produce in her facility.

ii) Partnerships made: A successful collaboration has developed between the Senegalese National Committee for Control of Malnutrition (Cellule de Lutte Contre la Malnutrition, CLM) and Mme. Mbacke (who is also a leader of a women's food processing economic group, GIE Touba Darou Salam), through the FPL and USAID-ERA project. The goal of the partnership is to supply instant fortified millet flours to Diourbel Region to help in the fight against malnutrition. In 2017, CLM (Table 9 made orders of about 20 cubic tons/19,716 kg instant fortified flour). In 2018, CLM ordered 6525 kg from Mme. Mbacke who worked with another processor association (GIE Sokhna Aminata Lo) to distribute. Overall, Mme. Mbacke struggled to meet the high demand. More new orders are expected this year, since CLM requires over 577 tons of the instant flour to be distributed in other regions of Senegal. As a result, ITA and FPL are looking for other sources of funding to buy a large-scale extruder or several of the currently used mini-extruders to meet the demand.

iii)

**Table 9.** Delivered orders of fortified instant millet flours to CLM in 2017.

| Zones | Ordered quantities in kg |
|---|---|
| Diourbel district | 4424 |
| Mbacke department | 3066 |
| Touba District | 11204 |
| Mbacke District | 4088 |
| Louga Department | 3524 |

NB: This table includes some orders from CLM in 2018.

Talks and/or proposals are in process with various organizations to expand the production using the "Hub and Spoke" food innovation system:

- African Development Bank
- World Food Programme
- Senegalese government authorities
- USDA-CLUSA/PSEM

FPL and ITA representatives participated in the opening ceremony of a new processing wing of Mme. Mbacke's GIE Touba Darou Salam processing unit (Figure 15). The new wing was designed to meet the hygiene and safety standards for supplying products to the United Nations International Children's Emergency Fund (UNICEF) and the World Food Programme. It will be used to process:

- Process high quality instant fortified infant foods and instant couscous and "arraw"
- Help to build a strong unit that can provide more revenues, training and increased production capacity

(a) At the entrance of the new facility

**(b)** Inside the new processing facility

**Figure 15.** Opening ceremony of the new processing facility of Touba Darou Salam processing unit. In Fig. 1(b) from the left to the right: Fallou Dieye (Special Advisor for Agriculture of the Prime Minister of Senegal), Madame Awa Diop Mbacke (Vice Consulate of Senegal in Paris), Mamadou Mbacke Fall (Sub-Prefect of Touba), Madame Sokhna Mbacke (Private processing partner of the FPL project and President of GIE), Moustapha Diakhate (Cabinet Director of the President of Senegal); Madame Lena Savelli (Director and Representative of WFP in Senegal); Bruce Hamaker (processing-nutrition PI of FPL), and Mamadou Amadou Seck (Director General of ITA).

iv) **Technologies ready to scale**: instant nutritious food products and "Hub and Spoke" food innovation system
v) **Technologies transferred:** instant fortified (nutritious) food products
vi) **Technologies scaled:** instant fortified (nutritious) food products

VI) Environmental Management and Mitigation Plan (EMMP)

FPL is committed to addressing potential environmental issues as outlined in the Environmental Mitigation and Monitoring Plan (EMMP). In Senegal, two complete individual protection equipment sets were acquired by ISRA for working with the insecticide-impregnated A to Z Textile hermetic bags. Upon completion of the study, the stored grain was incinerated to avoid entering into the supply chain. There is a protocol in place for safe disposal of the grain and bags at the end of the study.

VII) Open Data Management Plan

The FPL Data Management Plan (DMP) was submitted to the activity manager in August 2015. A total of nine 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 are 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.

Changes made since submission:

- The nutrition study will be conducted in Kenya and not Senegal as previously reported.
- New datasets added:
  - Impact assessment of promising technologies
  - Willingness to pay studies in both components, i.e. drying/storage and processing/nutrition.
  - Hygrometer development and assessment data

- Solar dryers development data

VIII) 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 advises 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. Over the last three years, the project held annual half-day WebEx meeting. However, this year the project held a 2.5-day face-to-face meeting on June 18-20, 2018 in Dakar, Senegal. The goals of the meeting were: 1) to critically assess FPL progress across the research to outcome continuum (i.e. since inception in May 2014) and seek other stakeholder's input; 2) to provide a comprehensive analysis of Year 4 results and outcomes; and 3) to outline plans for Year 5. The meeting highlighted the significant progress the FPL project has made toward its goals. For example, accomplishments made under the drying and storage component of the project include: 1) developing a low-cost moisture measurement protocol using the hygrometer that is conventionally used to measure relative humidity in the air and costs approximately USD 2.00 per unit); 2) developing two low-cost solar dryers that are currently being tested on-farm in the focus countries; 3) creating cost-effective aflatoxin-reducing innovations packages that consist of combinations of training on best post-harvest handling practices, use of low-cost grain moisture verification tools, tarps to eliminate drying on the ground, and hermetic storage bags; and 4) training over 7,000 farmers and traders on best practices for post-harvest drying and storage in Senegal and Kenya. Accomplishments in the processing and nutrition area include: 1) introduction of novel food processing technologies such as the extrusion technology (a precooking process used to produce instant or ready to eat flour-based products); 2) development of high quality, market-competitive, and nutritious food products that meet consumer demands; and 3) introduction of the "Hub and Spoke" Incubation/ Innovation Centers to disseminate food and nutrition technologies and to strengthen local food processing enterprises. Since the meeting was very productive and the project team recommended annual face-to-face meetings be conducted in the future.

IX) Other Topics[20]

Dr. Cheryl O'Brien, Assistant Professor at San Diego State University and a gender consultant for FPL, continued to provide input and guidance for project teams on gender issues when requested. Teams continued collecting gender-disaggregated data and sought Dr. O'Brien's input, as needed. A manuscript is being prepared for publication in a peer-reviewed journal for the gender-focused study that was conducted in the summer of 2016. In winter 2018, Dr. O'Brien conference-called with IFPRI Gender Specialists on WEAI-adaptation challenges and opportunities. Based on the study results as well as additional research beyond FPL, O'Brien will prepare a summary report of how men and women access grain drying, grain moisture determination and storage information to inform gender sensitive extension efforts. 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, thus provides a linkage

[20] Such as Regional Centers of Excellence, impact assessment, gender initiatives

between the two innovation labs (FPL and PHL) with regard to gender issues. She is exploring collaborative publishing options for cross-national findings and/or insights on gender issues.

X) Issues and how they are being addressed[21]

a) There was a four months delay in the release of 2017/18 fiscal year funding from USAID, which delayed the start of project activities. The beginning of the US government fiscal year coincides with harvest time in the focus countries, which is the peak of post-harvest activities. Funds are thus, needed right at the start of the fiscal year. Continued delays in release of funding can cost the project a whole season of activities. The effects are more profound for the sub-awardees who often do not have other resources at their disposal to continue to work. In an effort to remedy the situation, the project has been gathering all carry over funds to send to the subs in dire need.
b) 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.

XI) Future Directions

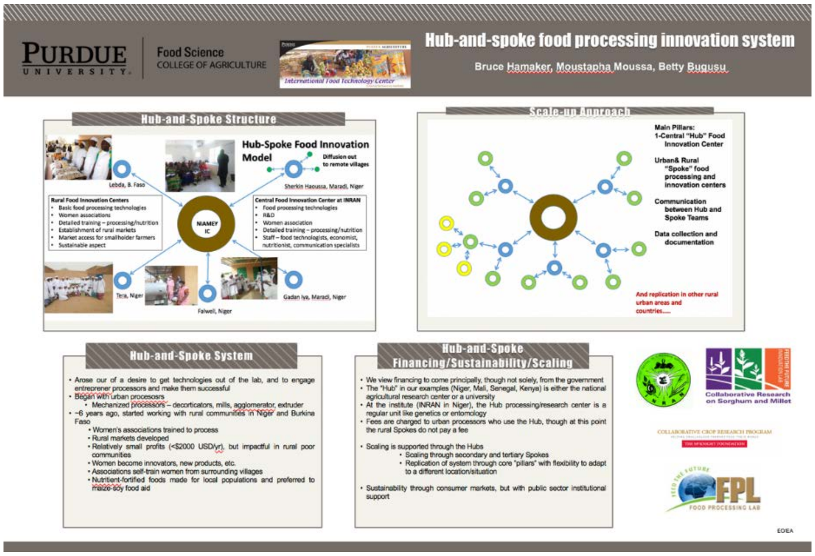
The FPL continues to find ways to be effective and relevant in the two focus countries of Kenya and Senegal through development of practical and cost-effective solutions for grain drying, storage, and food processing in the humid topics. The solutions will be beneficial to end-users including smallholder 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 target markets and households. 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 Year 3, emphasis is on field-testing and technology adaptation/refinement to environments of operation, and selection of viable technologies for adoption. In Year 4, the program focused on aspects of technology adoption, scale-up, and assessment of potential for commercialization of viable technologies. There is growing interest in the FPL technologies as judged by the various stakeholder interests. Private sector engagement is on the increase showing great potential for commercialization of the technologies. Overall, FPL has leveraged over $2 million in additional post-harvest research funding from various sources. In Year 5, the FPL will ramp up efforts to disseminate and commercialize the promising technologies, train more farmers, traders, and processors, and work closely with the private sector and other programs such as PICS to expand the reach of the technologies. The processing and nutrition team aims to introduce a market-led fortification strategy, which will provide affordable locally processed nutritious products that consumers want to eat. In addition, the FPL will work to link the two project components to make improvements across the entire post-harvest value chain that will enable food processors to source clean and safe grain from the farmers who benefit from the drying and storage innovations. The FPL also continues 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.

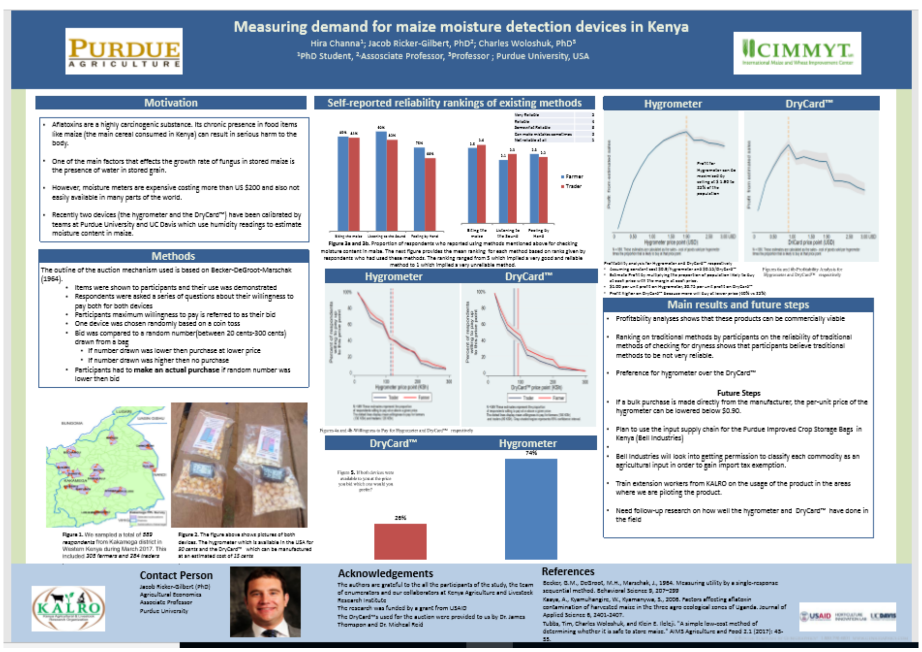
[21] Such as financial, management, regulatory

**APPENDICES**

**Appendix A:** Dr. Violet Mugalavai's poster presented at the Purdue University's Scale-up conference

**Appendix B:** Posters for two innovations (hygrometer and “Hub and Spoke” food innovation system) presented for assessment of scalability at the Scale-Up Conference held at Purdue on September 25-27, 2018



**Appendix C:** Expert assessment of the scalability of FPL generated innovations: hygrometer and "Hub and Spoke" food innovation system: Summary of feedback by Expert Panel

FPL submitted two innovations for expert panel assessment namely:

1) A hygrometer-based method for measuring moisture content of grains. The method is based on a low-cost Mini Digital Hygrometer that gives a temperature/relative humidity reading. Equilibrium RH of 65% at temperature of 20-30C indicates a moisture content of 12.5 to 13.5% (15-20 min). The hygrometer retails for <$2.00 in the USA. Purdue, CYMMYT, and KALRO have partnered with Bell Industries, a local company in Kenya to test market the sale of hygrometers in East Africa.
2) The "Hub and Spoke" Food Innovation System for disseminating of food processing and nutrition technologies and strengthening food processing businesses. The "Hub" is a central food technology-based facility housed at a local institution (National Agriculture Research Centers, NARS or universities).
    a. The "Hub" provides various functions including R&D, training, and technical support for entrepreneur processors.
    b. The "Spokes" are business units that make and sell products. They can be women associations or youth groups, principally in rural communities, or individual processors in urban areas. They process using technologies and formulations developed at the Hubs, but also innovate themselves (e.g. bring new product concept ideas for R&D)

**Technology Assessment Process**: It involved a short presentation on the technology or innovation by the principal investigators, followed by a three-member expert panel asking clarifying questions and providing feedback on ways to boost the innovations for scale-up.

**Summary of Feedback obtained**: Overall, the feedback received was very useful including evaluation of key strengths and weaknesses relative to readiness of the innovation for scale-up and suggestions for scalable pathways. We plan to incorporate this feedback in our scaling efforts.

**<u>Hygrometer-based method feedback:</u>**

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

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

**<u>Hub-and-spoke food innovation system feedback</u>**

1) Hub is performing a number of functions, thus should not be looked at a single unit, but rather need to tease out the roles in order to establish units/institutional structures; the most apparent are:
    a. Public community-serving Unit that is funded by the government for the greater good e.g. to provide R&D and training functions
    b. Private Unit for income generation to serve as launch pad for food processors (acts as a traditional incubator/accelerator). If successful will drive scale and sustainability
        i. Can start as a public private partnership and over time become a revenue

generator if successful will help the business scale-up and become sustainable

    ii. Crowd in private investors
    iii. Position it for impact investing

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

**Appendix D:** A. Three distinct success stories

**1. Commercialization of a Low-Cost Grain Moisture Measurement Device and Protocol**

The hygrometer-based method for measuring moisture content of grains is based on a low-cost Mini Digital Hygrometer that gives temperature and relative humidity readings. Equilibrium RH of 65% at temperature of 20-30C indicates a moisture content of 12.5 to 13.5% (15-20 min). The hygrometer retails for <$2.00 in the USA.

Commercialization of the hygrometer method was initiated in collaboration with the local private sector in Kenya and Senegal. This was done alongside the Purdue Improved Crop Storage (PICS) bags that have an emerging supply chains in both countries. Purdue and its local partners in Kenya (CYMMYT and the Kenya Agriculture and Livestock Research Organization, KALRO) worked in collaboration with Bell Industries, a local company that manufactures and markets PICS bags. Bell Industries participated in the FPL-sponsored training workshops conducted. They also acquired hygrometers through FPL to test the market. Extension activities were conducted in both countries on the hygrometer, solar dryers (FPL-generated), and hermetic storage bags. Over 2000 farmers and traders were trained on these technologies and other post-harvest handing practices. In Senegal, Purdue partnered with ISRA (FPL local collaborator), and two local extension agencies (SEDAB and ANCAR) to conduct trainings. COFISAC/FUMOA, a local company that manufactures bags, has been in talks with Purdue Global to obtain a license for manufacturing PICS bags. The local company will also market hygrometers.

Together, FPL and PICS have worked to add a plastic jar to the hygrometer to make it a more standardized product compared to placing the device in a plastic bag containing grain (50g) for testing (Figure 1). Dieudonne Baributsa (Director, PICS Program at Purdue) has engaged PICS bags manufacturers on the possibility of producing a hygrometer product to be sold through the PICS supply chain. Additionally, Global Good continues to work on refining and improving the hygrometer, hoping to have a new prototype of the device ready for the market testing by the end of 2019.


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

The FPL hygrometer was submitted for scalability assessment by a team of scaling experts during the Scale-Up Conference held at Purdue on September 25-27, 2018. The team received useful feedback that is being incorporated in the commercialization efforts.

**2. “Hub and Spoke” food innovation system for disseminating of food processing and nutrition technologies and strengthening food processing businesses.**

The “Hub and Spoke” Food Innovation System was developed through a series of projects funded by USAID and other donors to find ways of fostering the local food processing sector in developing countries. The goal of the system is to disseminate food processing and nutrition technologies and to strengthen food processing businesses. The “Hub” is a central food technology-based facility housed at a local institution (National Agriculture Research Centers, NARS or universities). The “Hub” serves various functions including R&D, training, and technical support for entrepreneur processors. The “Spokes” are business units that make and sell products. They are often women associations or youth groups, principally in rural communities, or individual processors in urban areas. They process using technologies and formulations developed at the Hubs, but also innovate themselves (e.g., bring new product concept ideas for R&D). The system has been developed and refined further under the FPL and Sorghum and Millet Innovation Lab.

In 2018, the Rockefeller Foundation awarded Purdue a grant ($525K) to expand the “Hub and Spoke” Food Innovation System in Kenya and Tanzania, under their YieldWise project.
In Senegal, FPL and ITA (local partner) have worked closely with a local philanthropist, Mme. Mbacke, to expand the concept to Touba, a semi-urban region in the country. The success of the program has attracted the attention of the Government of Senegal officials and other organizations.
Talks and/or proposals are in process with various organizations to expand the “Hub and Spoke” food innovation system including:

- The government of Senegal’s National Committee for Control of Malnutrition (Cellule de Lutte Contre la Malnutrition, CLM)
- World Food Programme
- USDA-CLUSA/PSEM project
- The African Development Bank

The FPL also submitted the “Hub and Spoke” food innovation system for scalability assessment by a team of scaling experts during the Scale-Up Conference held at Purdue on September 25-27, 2018. The team received useful feedback that will be incorporated in the commercialization efforts.

**3. Commercialization of the DEHYTRAY™**

JUA Technologies International LLC. (JTI), a start-up company founded by Ileleji (FPL PI), is commercializing the two multipurpose solar dehydration devices successfully registered under two trademarks with the United States Patent and Trademark Office: the DEHYTRAY™ (multipurpose solar drying tray) and the DEHYMELEON™ (multipurpose solar dryer and power generator). Improvements were made to the DEHYTRAY™ by redesigning a more efficient solar collector. The first version of the electronics control system that would enable the solar dryer to run automatically and efficiently with the new solar collector has been completed by JTI as part of the effort toward commercial production. The goal is to transfer most of this heat gain from the collector to the drying chamber by using our electronic control system. JTI is pursuing grants from NSF and USDA SBIR programs to refine the DEHYMELEON™ for commercialization.

Dr. Ileleji visited several potential partners that could play a role in commercializing the technologies in Senegal and Kenya during the FPL team’s in-country trip to conduct train-the-trainer workshops. In Senegal, the team visited SEDAB (seed producer) and Madam Mbacke’s facility (Purdue/ITA Food Processing Hub) in Touba. The DEHYTRAY™ and hygrometer were demonstrated for use in drying extruded instant mix at the Touba facility. In Kenya, the team visited Bell Industries, Trans-Nzoia Ministry of Agriculture, Kenya Cereal Enhancement Programme (KCEP), and KALRO in Nairobi, Kenya Industrial Estates (KIE), and Quipbank/TingA Project (serves 2,000 farmers with machinery services in

Kenya).

JTI has engaged with an Indiana-based company to manufacture the DEHYTRAY™. JTI invested in product design for manufacturing, parts prototyping/testing, and injection mold manufacture. Injection molding technology is used to manufacture the DEHYTRAY™, using a polymers that are not easily degraded by ultraviolet light as well as approved by the Food and Drug Administration for food contact. The DEHYTRAY™ comes in three parts, which can be intuitively and easily assembled. It weighs about 3.5 lb (1.6 kg) when assembled and holds up to 20 lbs (9 kg) of maize (corn) per batch for drying stand-alone. Testing of the first manufactured units has been taking place since June 2018 at Purdue and with various JTI partners (Fort Valley State University in Georgia, USDA-ARS Lab in Albany and at a farm in Brentwood, California, and Oregon). Three samples were provided to the FPL project team in Senegal and Kenya for demonstration and brief testing. Initial reviews of the DEHYTRAY™ by various stakeholders and USAID Kenya Mission staff were quite positive. Figure 2 shows the DEHYTRAY™ being tested for drying extruded instant cereal mix at Madam Mbacke's processing facility in Touba, Senegal. Results of various tests of the DEHYTRAY™ show that:

- The temperature within the tray increases to twice the ambient temperature in less than 30 minutes, thereby increasing crop drying rate.
- Drying rate of the DEHYTRAY™ exceeds ambient open sun-drying, especially in poor weather conditions.
- The DEHYTRAY™ provides a better phytosanitary drying environment.

**Figure 2.** DEHYTRAY™ being demonstrated at Touba Darou Salaam Cereal processing facility in Touba, Senegal.