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

ANNUAL REPORT

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LEAD UNIVERSITY

Purdue University

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LIST OF COUNTRIES WHERE THE PROJECT WORKS

Kenya and Senegal

LIST OF PROGRAM PARTNERS[1]

- ***USA:*** North Carolina A&T State University and North Carolina State University
- ***Kenya:*** University of Eldoret; Kenya Agricultural and Livestock Research Organization; and CIMMYT, Kenya
- ***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	Advisory Council
ACRE	Agronomy Center for Research and Extension
ASABE	American Society of Agricultural and Biological Engineers
ASTM	American Society for Testing and Materials
CIP	International Potato Center
CRT	Powdered carrot
DDL	Development Data Library
DMP	Data Management Plan
DOIs	Digital Object Identifiers
FGDs	Focus Group Discussions
FPL	Innovation Lab for Food Processing and Post-harvest Handling
KALRO	Kenya at the Kenya Agricultural and Livestock Research Organization
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ISRA	L'Institut Sénégalais de Recherches Agricoles
ITA	Institut de Technologie Alimentaire
NCA&T	North Carolina A&T State University
NIST	National Institute of Standards and Technology
OFSP	Orange-fleshed sweet potato
PICS	Purdue Improved Crop Storage bags
PHL	Post-Harvest Innovation Lab, Kansas State University
PMP	Pearl millet-based porridge
POD	Picosolar crOp Dryer
PPB	Parts per billion
PURR	Purdue University Research Repository
RH	Relative Humidity
SC	Steering Committee
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 April 1, 2017 to September 30, 2017. Some instances, activities from the previous reporting cycle (October 1, 2016 to March 31, 2017) are included to make the report more informative. Overall, FPL continued to make progress in all key aspects of the program including: 1) development of simple moisture determination methods; 2) development of low-cost grain drying technologies; 3) testing of efficacy of hermetic storage bags such as PICS for moisture, aflatoxin accumulation, and pest control in hot and humid tropics; 4) quantitative assessment of market demand and drivers for instant food products, with and without nutritional enhancement; 5) development and/or refinement of food products and processes to drive markets in Kenya and Senegal; 6) leveraging local nutrient-rich agriculture commodities to produce nutritionally-enhanced food products and to create a sustainable market-led fortified processed foods; and 7) strengthening of the incubation center platform for effective disseminate food technologies. This last six months of the fiscal year focused on refinement of developed technologies, continued field-testing, and adoption of developed technologies through engagement with country extension staff, farmers, traders, and food processors. The monitoring and evaluation team was very active in administering developed technologies and assessing their potential for uptake. The research, outreach, and monitoring & evaluation efforts provided a platform for strengthening existing and establishing new public-private partnerships.

II) PROGRAM ACTIVITIY HIGHLIGHTS[2]

- Aflatoxin intervention initiative in Senegal to determine the most cost-effective way to prevent aflatoxin contamination and spread in the maize supply of rural subsistence households.
- Testing and refining the developed solar dryer prototypes (multipurpose and Picosolar crOp Dryer, POD) in USA, Kenya, and Senegal.
- Testing the efficacy of hermetic bags (PICS and A to Z Textile) with regard to moisture, aflatoxin accumulation, and pest control for maize storage in Kenya and Senegal.
- Strengthened existing and established new public-private partnerships in support of research and outreach activities:
    - Purdue, CYMMYT-Kenya and KALRO partnered with Bell Industries, a local company in Kenya, which markets other Purdue technologies and is interested in the hygrometer to test market the sale of hygrometers in the East Africa region. Trainings and demonstrations are being conducted.
    - Purdue is partnering with Global Good (a collaborative effort between Bill Gates and Intellectual Ventures to address some of humanity's toughest problems through the power of invention) to develop and later to evaluate protocols that use inexpensive humidity/temperature devices to measure moisture content of grains
    - Purdue partnered with USAID FtF Agriculture Diversification (AgDiv) Program and Purdue PICS program to conduct two train the trainer workshops in Malawi, which included hands-on activities using the hygrometer and hermetic storage (PICS Bags).
    - University of Eldoret partnered with local companies to supply ingredients for product development including: Organi Ltd. in Kisii County - processors of orange fleshed sweet

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

potato (OFSP); Nyapalo Farmers' Cooperative in Homabay County – farmers of OFSP; AWRICO Health Millers in Bungoma County - processors of grain amaranth; sorghum farmers from Matayos in Busia County and maize farmers from Uasin Gishu and Elgeyo Marakwet Counties to supply grain at a lower cost; and International Potato Center (CIP) in KENYA to provide technical support on use of OFSP as a fortificant.
    - ITA worked to strengthen the partnership with Darou Salam Cereal Processing Unit., owned by Mme. Mbacke, a key local partner in Touba.
- Development of various products:
    - Extruded naturally-fortified (cereal/nutrient-rich plants) formulations for use in Kenya and Senegal.
    - Weaning food formulations using local crops (millet, cowpea, peanut butter) and the nutrient-rich crops (baobab flour/bouye and carrots) as well as vitamin and mineral mixes for Senegal.
- Participation in conferences, exhibitions and trade fairs to demonstrate and promote effective technologies and publication of peer-reviewed journal articles.

III) KEY ACCOMPLISHMENTS[3]

- The multipurpose solar dryer with trays half-filled and all fans working was faster (1.4 times) for drying maize grains than drying in the open air or on tarp.
- Hermetic bags were more efficacious than the woven bags against insects and aflatoxin accumulation for maize stored at 13% compared to maize stored at 18% moisture content.
- New partnerships and collaborations were established to advance research and technology transfer
    - Partnered with Bell Industries, a local company in Kenya, to test market the sale of hygrometers in the East Africa region.
    - Signed an agreement with Global Good to develop and later to evaluate protocols that use inexpensive new generation humidity/temperature devices to measure grain moisture.
    - Partnered with various public and private entities at the University of Eldoretas follows: 1) to supply ingredients for product development (Organi Ltd., Kisii County; Nyapalo Farmers' Cooperative, Homabay County; AWRICO Health Millers, Bungoma County and grain farmers from Busia County, Uasin Gishu, and Elgeyo Marakwet Counties; 2) to provide technical support on natural fortification (International Potato Center, CIP in Nairobi, Kenya; and 3) training of processor in partnership with ICRISAT.
    - ITA strengthened the partnership with Darou Salam Cereal Processing Unit., owned by Mme. Mbacke, a key local partner in Touba.
- Developed various food product prototypes using local crops (millet, cowpea, peanut butter) and the nutrient-rich crops (baobab flour or bouye, carrots and moringa) as well as vitamin and mineral mixes including extruded naturally-fortified blends and weaning food formulations for Kenya and Senegal.
- Increased consumer acceptability and willingness to pay for developed food products including instant flour-based and naturally fortified products that are attracting donor and government interest.
- Fifty-seven food processors trained at the University of Eldoret.
- 23 graduate students have been recruited since program inception: 15 male and 8 female; 14 Ph.D. and 9 Masters. Four of the students are supported on research only. The students come from Kenya, Senegal, Ethiopia, Uganda, Botswana, Nigeria, South Africa, Ecuador, and USA.

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[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.

- Three students, two from US and one from Nepal completed their MS degrees at Purdue University
- One MS student from Kenya was recruited during the reporting period

- Several papers have been published by various researchers on the project.

IV) RESEARCH PROGRAM OVERVIEW AND STRUCTURE

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

V) RESEARCH PROJECT REPORT[4]

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

Activity 1.1: Aflatoxin intervention initiative

i. Description: conducting Aflatoxin tests on 1,583 maize samples from 1,993 smallholder households who had maize in storage and underwent training and technology introduction in the previous harvest season. The goal of the study was to identify which combination of training and technologies had the largest impact in lowering aflatoxins in the households.
ii. Location: Velingara, Senegal
iii. Collaborators[5]: Jacob Ricker-Gilbert, Jonathan Bauchet, and Charles Woloshuk (Purdue) and Ibrahim Sarr (ISRA, Senegal);
iv. Achievements:

The main research question that motivates this study is: What is the most cost-effective way to prevent aflatoxin contamination and spread in the maize supply of rural subsistence households in SSA? To answer this question, a randomized intervention was set-up in the Vélingara region of southern Senegal. First, a baseline survey was conducted in 209 villages (1,993 households) in May 2016. Just before the next harvest in October 2016, households were randomly assigned to a control group (Group 1) and four treatment groups (Groups 2-5).

In collaboration with ISRA, the premier agricultural research institution in Senegal, we trained Groups 2-5 (1,611 households) on improved drying and storage practices. Group 2 did not receive any technology. Groups 3-5 (1,217 households) received hygrometers as a low-cost grain moisture verification tool that can be used to determine when maize is dry enough for safe storage. Groups 4-5 (819 households) received a 10m^2 plastic sheet as an alternative to drying maize on the ground. Group 5 (409 households) received one Purdue Improved Crop Storage (PICS) container as a means of preventing insect contamination and limiting any fungus growth in storage. PICS containers hermetically seal maize, limiting oxygen and increasing carbon-dioxide, which kills any insects in the grain during storage. The total investment cost of the interventions per household before labor costs, was estimated to be \$6.62 – \$9.37.

All households were surveyed again in January/ February and May 2017, to determine which households implemented recommended practices and to test the aflatoxin levels in their stored maize.

[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.

Results: In the study setting, 99% of households consume their own maize, 70% retain their own seed, and only 7% sell their maize. Preliminary results indicate that simple training is important in increasing household knowledge of aflatoxin's toxicity (Table 1). The percentage of farmers who think aflatoxins are harmful is only 18% in the control group but 63-76% in the treated Groups 2-5.

Additionally, Table 1 shows that Groups 4-5 who received a plastic sheet on which to dry their maize were statistically less likely to dry on the ground than all other groups. An unanticipated treatment effect was observed in Groups 2-5 such that they were statistically more likely than Group 1 to still have stored maize from the Fall 2016 harvest in January/February 2017. A possible reason is that Groups 2-5 were able to dry and store maize of better quality than control households, so they held onto it longer and consumed other foods first.

Table 1. Key results from post-intervention, February 2017

	Number (%) of participants		
	Believe aflatoxin is toxic	Dried maize on ground	Had maize in storage in Feb 2017
1) Control	69 (18%)	52 (8%)	161 (42%)
2) Training Only	247 (63%)	45 (7%)	212 (54%)
3) 2 + Hygrometer	294 (76%)	43 (10%)	219 (57%)
4) 3 + Plastic sheet	283 (70%)	21 (5%)	255 (63%)
5) 4 + PICS bag	273 (68%)	17 (5%)	249 (62%)
TOTAL	**1,166 (59%)**	**178 (9%)**	**1,096 (55%)**

Preliminary aflatoxin results (Table 2) show that households that received the training and all technologies (Group 5) had the lowest aflatoxins levels, and the largest percentage of samples below 10 and 20 parts per billion (ppb). Figure 1 also shows that Group 5 had the lowest mean aflatoxin level, at 11.39 ppb. Despite the provision of a plastic sheet as an improved drying surface to avoid drying directly on the ground, there was no significant difference in aflatoxin outcomes between Group 2-4; while all groups were significantly different from the control group, Group 4 was only weakly significant.

Table 2. Aflatoxin results by treatment group

	Number of samples (% of treatment group samples)		
	Samples analyzed	≥ 10 ppb	≥ 20 ppb
1) Control	242	81 (33%)	70 (29%)
2) Training Only	301	77 (26%)	64 (21%)
3) 2 + Hygrometer	295	78 (26%)	70 (24%)
4) 3 + Plastic sheet	371	112 (30%)	95 (26%)
5) 4 + PICS bag	375	76 (20%)	58 (15%)
TOTAL	**1,584**	**424 (27%)**	**357 (23%)**

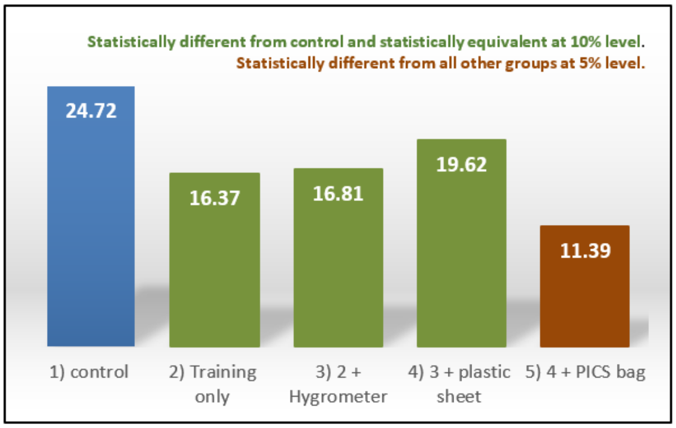


Figure 1. Average aflatoxin levels by group (ppb)
**The 134 samples measuring > 100 ppb were calculated at 100 ppb. Sample average is 23 ppb.*

Lessons Learned: Overall these findings provide some important preliminary insights. The fact that drying on the ground is reduced through provision of a plastic sheet directly addresses the issue of a safe drying surface. In addition, the fact that Group 5, which received the hermetic bag had the lowest mean aflatoxin level suggests that drying and storage practices go together for smallholder households. Therefore, if smallholder farmers receive training on best practices and a safe place to store maize, they may make efforts to find a clean place to dry it before putting in a hermetic bag; thus leading to safer, higher quality maize for consumption. Further research of the behavioral connection between drying and storage decisions is ongoing.

References:
Gajate-Garrido, G., Hoffmann, V., Magnan, N., Opoku, N. 2016. “Technological and Market Interventions for Aflatoxin Control in Ghana: Preliminary Findings.” Paper presented at AAEA annual meeting, Boston MA, July 31 - August 2.
Williams, S.B., D. Baributsa, and C. Woloshuk. 2014. "Assessing Purdue Improved Crop Storage (PICS) bags to mitigate fungal growth and aflatoxin contamination." Journal of Stored Products Research 59:190-196.

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

i. Description: Develop low cost moisture determination methods
ii. Purdue, USA, Dakar, Senegal and Kakamega, Kenya
iii. Collaborators[6]: Charles Woloshuk (lead), Klein Ileleji, Patrick Ketiem (KALRO, Kenya); Hugo DeGroote (CIMMYT, Kenya); Ibrahim Sarr (ISRA, Senegal); Guibing Chen (NCA&T, USA).
iv. Achievements:

<u>1.2.2 Develop and evaluate moisture content testing protocols that use inexpensive humidity/temperature devices</u>
The project team (Jake Ricker-Gilbert, Dieudonne Baributsa and Charles Woloshuk) has had continuing talks with Global Good personnel on the hygrometer protocol for measuring grain moisture developed under FPL. The team had several conference-call meetings and a site visit to Purdue on August 15. They shared designs for a low-cost hygrometer and a capacitance-based moisture meter. Discussions are underway for an agreement for Purdue to test their devices and to assist their effort to market them in several African countries. The work will begin in November.

[6] Provide institutional affiliation and country.

Capacity Building:

1. Two train the trainer workshops were conducted in Malawi in May 2017 by Dieudonne Baributsa (PICS) and Charles Woloshuk (FPL) in collaboration with USAID FtF Agriculture Diversification (AgDiv) Program. The training included hands-on activities with the hygrometer and hermetic storage (PICS Bags).
2. Charles Woloshuk also joined the FPL Kenya team (Patrick Ketiem and Hugo De Groote) at the Kakamega Farm Show on June 15, 2017. The FPL booth, which was part of the KARLO exhibit, sold PICS bags and hygrometers. Several awards were given for the exhibit –see pictures in Appendix 1.

Lessons Learned:

Feedback on the hygrometer continues to be positive. It is best appreciated when the grain moisture is at the borderline, just above what is considered safe storage moisture (14%). People consistently think the grain is dry but when shown the hygrometer reading showing it is not, they express interest in buying one.

1.2.3 Determine impact of grain moisture on aflatoxin accumulation in hermetic storage

Prior to harvest, maize kernels are invaded by a diverse population of fungal organisms that comprise the microbiome of the grain mass. Poor post-harvest practices and improper drying can lead to the growth of mycotoxigenic storage fungi and deterioration of grain quality. A study explored the use of high-throughput DNA sequencing for characterization of the fungal microbiome before and after three months of storage in hermetic and non-hermetic (woven) bags in the United States and Kenya. Analysis of 1,377,221 and 3,633,944 ITS2 sequences from the US and Kenya, respectively, resulted in 182 and 164 operational taxonomic units (OTUs). Taxonomic assignment of these OTUs revealed 55 and 29 fungal genera in the US and Kenya samples, respectively, many of which were not detected by traditional plating methods. The most abundant genus was *Gibberella*, which was identified in all samples. Storage fungi were detected in the grain mass prior to the storage experiments and increased in relative abundance within the woven bags.

Capacity Building: Graduate student (Brett Lane) graduate from Purdue with MS degree.

Publications:

1. Lane, B. and Woloshuk, C. P. 2017. Impact of storage environment on the efficacy of hermetic storage bags. Journal of Stored Products Research. 72: 83-89.
2. Lane, B., Sharma, S., Niu, C., Maina, A.W., Wagacha, J.M., Bluhm, B., and Woloshuk, C.P. Characterization of the fungal microbiome associated with hermetically stored maize in the United States and Kenya. Phytobiomes (in Revision).

Lessons Learned:

The results indicate that the fungal microbiome of grain stored in the United States changed very little during storage, whereas the fungal microbiome of the Kenya grain changed significantly. The results also indicated that bag type was the most important factor influencing changes in fungal microbiome during storage.

1.2.3 Measurement of desorption-sorption isotherms for whole maize kernel

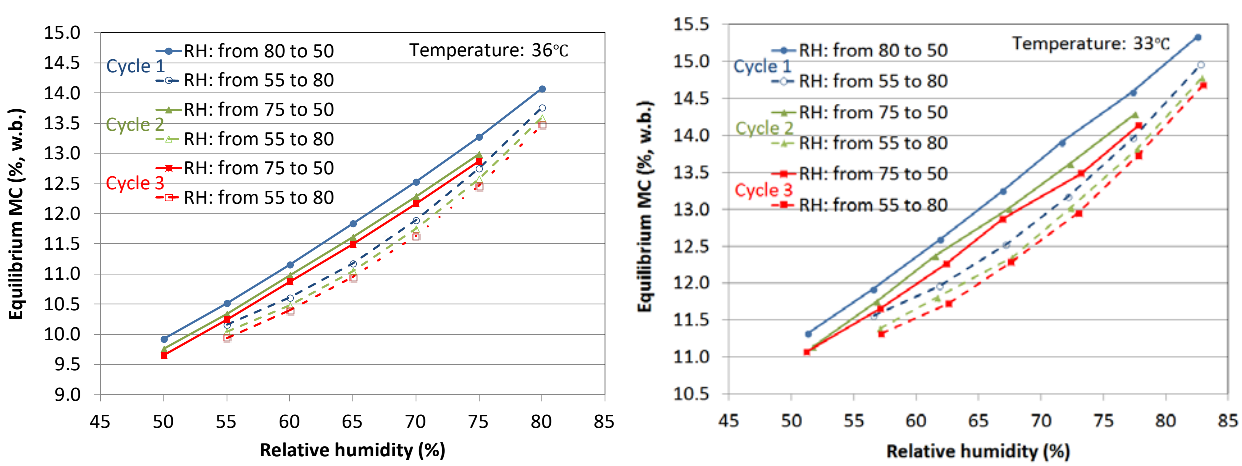
The objective was to determine errors caused by hysteresis in different drying-wetting cycles and to what extent and in what moisture range that it would contribute to errors in moisture determination using the hygrometer method. Yellow dent maize samples were purchased from Detwiler Native Seed Company (Bonham, TX). Moisture content in maize was determined using the AACC method (AACC, 1995). In this method, dry weight of whole maize kernels is determined by drying them at 103 °C ±1 °C for 72 hours. Effects of drying-wetting history on desorption-sorption isotherms were determined.
Desorption-sorption isotherms of 50 g whole maize kernel at a temperature range of 18-36 °C with 3 °C intervals and a relative humility (RH) range of 50-80% with 5% intervals were measured in a Caron Model 6020 environmental chamber (Caron Corporate, Marietta, OH) with controlled temperature and humidity. Under each condition (constant temperature and RH), the weight of a sample was recorded after equilibration for 24 hr. At each temperature, desorption-sorption isotherms were measured three times

(three cycles) using the same maize sample. Such measurements provided information on how drying and wetting history influences desorption-sorption isotherms.

Results: Figure 2 shows desorption-sorption isotherms for whole yellow-dent maize kernels with different drying-wetting histories at different temperatures. As seen in the figure, desorption-sorption isotherms at each temperature formed a hysteresis loop, and the desorption isotherm always took the upper part of the loop. The same phenomenon was also observed in a previous study (Shelef & Mohsenin, 1966). Moreover, at each temperature, a same sample with a different drying-wetting history exhibited a different desorption-sorption loop. For this reason, an equilibrium moisture content at a given temperature may correspond to different values of relative humidity. For example, RH corresponding to an equilibrium moisture content (EMC) of 13% (wet basis, w.b.) at 27 °C may be 71% (lower limit) or 77% (upper limit). The lower limit of RH should be taken to ensure the moisture content is safe for storage of the grain when using the hygrometer method. In addition, from Fig. 1, the lower limit of RH corresponding to a given EMC at a given temperature is always located on a desorption isotherm.
Figure 2 also indicates that a RH may correspond to multiple values of EMC at a given temperature. At each temperature, the differences between the upper limit and lower limit of EMC at each RH were calculated and their maximum values were listed in Table 3.

Table 3 Maximum differences in EMC at different temperatures

Temperature (°C)	Max. differences in EMC (%, w.b.)
18	0.7
21	1.2
24	1.3
27	0.8
30	0.9
33	1.0
36	0.9



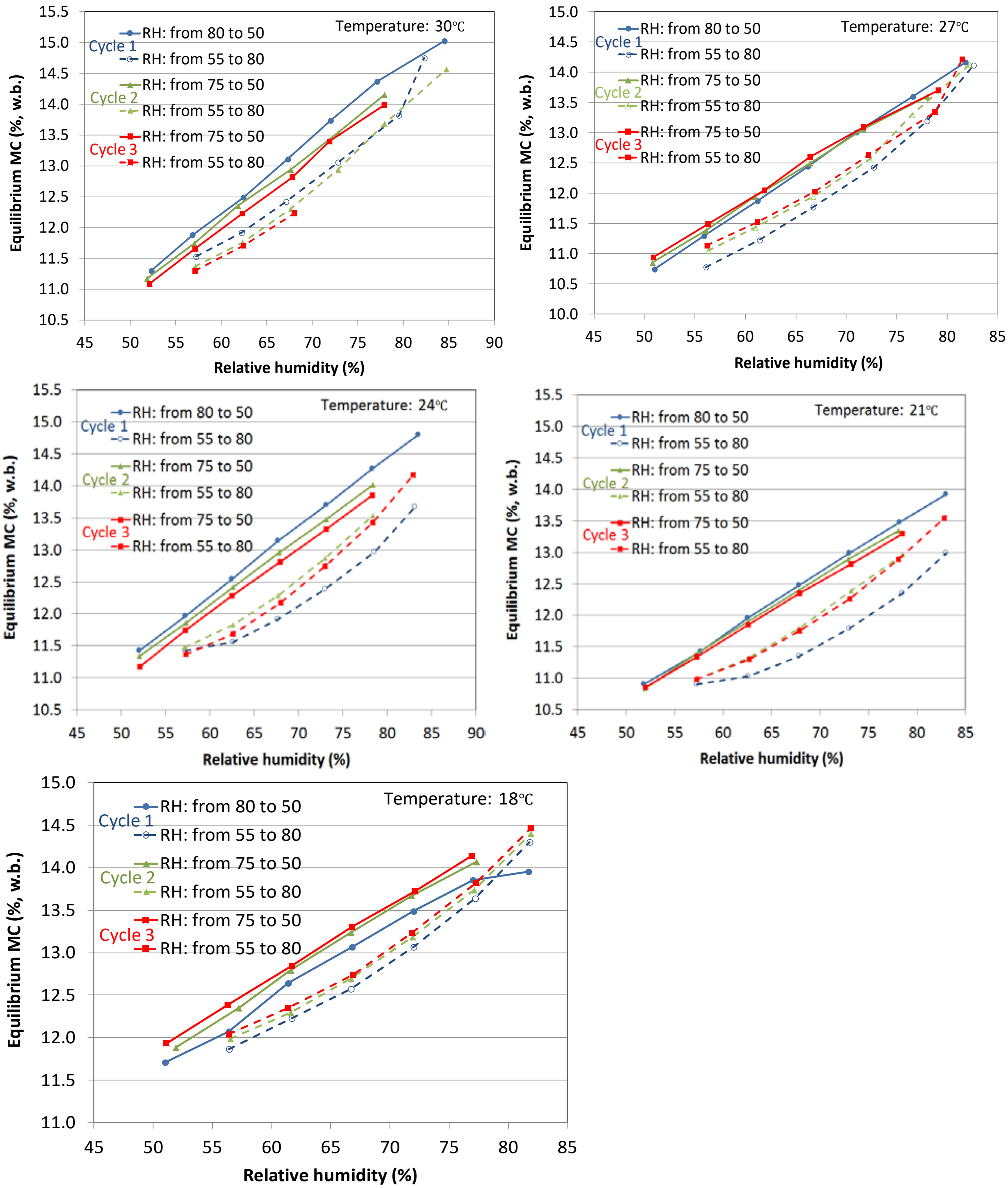


Figure 2. Desorption-sorption isotherms for whole maize kernel with different drying-wetting histories at different temperatures.

References

1. AACC Method 44-15A; ASTM; NIST; Kenyon, A.S., Black, J.C., & Layloff, T.P. (1995); J. Assoc. Off. Anal. Chem. 78, 1109-1111.
2. Shelef, L. and Mohsenin, N.N. (1966). Moisture relations in germ, endosperm, and whole maize kernel. Cereal Chemistry, 43, 347-353.

Activity 1.3: Development of grain dryers

i. Description – Develop low-cost grain drying for small holders
ii. Location: Purdue, USA, Dakar, Senegal and Kakamega, Kenya
iii. Collaborators[7]: Klein Ileleji, Charles Woloshuk, Arvind Raman, Richard Stroshine, Jess Lowenberg-DeBoer, Patrick Ketiem (KALRO, Kenya); Hugo DeGroote (CIMMYT, Kenya); Ibrahim Sarr & Katim Toure (ISRA, Senegal); Guibing Chen (NC A&T, USA)
iv. Achievements:

1.3.1 Low cost on farm solar grain dryer for small holder farmers in Africa Solar Pico CrOp Dryer (POD)

FPL researchers (Arvind Raman, Richard Stroshine) continued work to develop a low cost solar dryer for on-farm use. Socio-economic research has shown a market need among African smallholder farmers for on-farm photovoltaic-powered grain dryers that cost less than $100, 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 more affordable and are in the same price range as where the10W panels were 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.

Results

The first version of the low cost solar dryer assembled was the Solar Wrap Dryer, which consisted of a tarp on which maize was spread covered with plastic sheeting that was draped over the top of the tarp and tucked beneath it. The tarp was held in place with weights while a fan powered by a 20 W solar panel or 13 volt deep cell battery blew air into the pocket formed by the tarp and plastic. The egress of air from the dryer at the opposite end of the tarp was restricted, causing the plastic to "inflate" and form a dome over the drying maize. Tests during June through October of 2016 indicated that, although the Solar Wrap Dryer provided protection from birds, animals, and air borne contaminants, it did not dry the maize faster than laying the maize on a tarp and exposing it to sunlight. In fact, a side by side test indicated that a 45 kg batch of maize that could be dried to 13.5% MC in 3 days under reasonably strong sunlight required 4 days to dry to 13.8% MC using the solar wrap dryer. When the dryer was tested in Kenya in October of 2016 where the sunlight was stronger, it still did not perform better than the open tarp.

The results obtained from the Solar Wrap dryer, combined with discussions with colleagues at KALRO and CIMMYT in Kenya, led the investigators to examine alternate approaches to drying the maize in which air would be forced through the grain instead of blowing it over the grain surface. In open air drying scenarios, trays have been used to hold the product being dried. Therefore, a new design was developed that used wire mesh trays having a wooden frame. The new approach retained several positive features of the Solar Wrap Dryer. Those features were: 1) covering of the maize with plastic sheets which captures some of the sun's energy to heat the drying air; 2) use of a low cost fan powered by a 20 W solar panel; 3) use of a battery to power the fan when the solar panel does not provide sufficient energy; and 4) use of the electricity generated by solar energy that is not needed to run the fan to re-charge the battery. One of the first prototypes of this dryer is shown in Figure 3. At the time this picture was taken, it was being tested at KALRO, Kakamega. Wet maize was placed in 5 trays that were positioned side by side. Any space between the frames of adjacent trays was sealed with duct tape. The top of the trays were covered with two layers of plastic sheeting, first with a black sheet and then with a clear sheet. Air was blown into the "pocket" formed between the tray and the sheeting so that it inflated the sheeting and formed a small chamber above

[7] Provide institutional affiliation and country.

the maize. The trays were slightly elevated above the ground so that air could pass through the grain and the wire mesh trays and exit the dryer underneath the each tray. Both the black plastic and clear plastic sheets were used because results from the summer and fall 2016 tests with the Solar Wrap Dryer indicated that the black sheet beneath the clear sheet more effectively trapped heat from incoming solar radiation.

Figure 3. Solar POD dryer being tested by KALRO staff in Kakamega, Kenya, March 2017.

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

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

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

Table 4. Moisture Contents from the Dickey John moisture meter and the Oven Method (OM*)

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

*OM means 72 hour, 103°C, whole kernel oven test according the ASABE Standard S352
** Initial MC using OM was 18.86%

An indoor/outdoor thermometer was used to measure the ambient air temperature and the temperature of the air exiting the dryer trays. Initially, the exhaust air temperature was about 2°C below ambient and the temperature drop, after 5.75 hours of drying, when the shelled maize was at about 14.6% moisture was the same. This indicates evaporative cooling occurred as the air picked up moisture from the shelled maize.

The exhaust air temperature was only about 0.6°C below ambient at the end of drying on the second day (10.75 hours of drying) when the moisture of the shelled maize was about 13.0%. Therefore, there was still some evaporative cooling, indicating that drying was being accomplished. However, it was much less than on the previous day because the shelled maize was dryer.

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

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

After the initial testing was completed at Purdue, the POD dryer was sent to KALRO, Kakamega in Kenya, with instructions for assembly. The dryer was assembled (Figure 4) by Patrick Ketiem with additional support from Purdue team via Skype and various drying tests were conducted. The POD dryer was tested next to an open tarp and performance of both was monitored (Figure 5).

Figure 4. Preparation for the drying test comparing performance of the POD dryer with that of an open tarp. Tests were conducted by Mr. Patrick Ketiem and his assistants at KALRO in Kenya

Figure 5. Patrick Ketiem and assistant monitoring moisture content during a drying test at KALRO in Kenya

Results:
Figure 6 represents the drying test results showing moisture measurements made on maize from the tarp and on maize from each of the trays in the POD dryer. Unfortunately, the maize placed on the tarp was initially several percentage points wetter than the maize in the POD dryer. However, the drying lines have similar slopes, indicating that the drying rates for the two dryers were similar. In addition, the POD dryer maize dried down to 13.5% moisture whereas the tarp did not. The Solar POD dryer heated the air approximately 5°C above ambient temperature, thereby lowering its relative humidity to the point where it could continue to dry the grain even for higher ambient air humidity. One concern reported was that the drying was slower for the middle tray (Tray 3). This could be possibly due to uneven distribution of the solar heat within the POD dryer compartment.

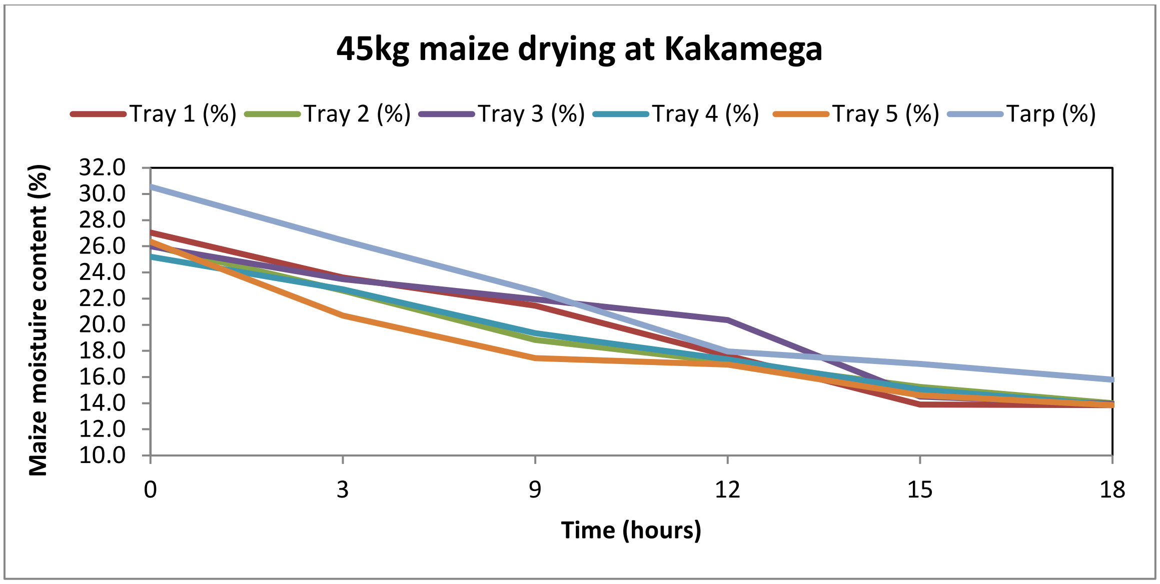


Figure 6. Summary of moisture measurements of maize drying on a tarp and of maize from each of the five trays of the POD dryer during an 18 hour drying test conducted at KALRO using 45 kg of maize.

Additional tests (a total of six) were conducted on the POD dryer design at Purdue (by Stroshine and Raman) over the period of June to September 2017. Drying was scheduled during periods of sunny weather, although it was often partly cloudy on those days, thus solar radiation was less than optimum for drying. The first three tests used the dashboard fan consisting of two adjacent fans secured to a pedestal. It was designed to be affixed to the dashboard of a car and connected to the car's cigarette lighter. The first test used five rectangular wooden trays that were 76 cm long and 46 cm wide (30 in. by 18 in.) with a depth of 4.4 cm (1.75 in.) holding approximately 50 kg of wet maize. This test set-up was similar to the one conducted in Kenya in March, 2017 except that the trays were wider. In test #1, drying began at 9:30 hrs and the fan ran continuously until late afternoon of the second day.

Results:
Results are summarized in Table 5.

- Test #1, at 17:00 on the first day of drying, the average maize moisture content in the 5 trays was 13.5%. The relative humidity was high overnight. By morning the following day, the average moisture of the five trays had increased to 13.9%. This underscored the importance of stopping the fans when the maize is relatively dry (e.g. below 15%) and the relative humidity of the drying air is above 60%.
- Test #2, the same trays (depth of 4.4 cm) were used, and the maize had an initial moisture content of 27.9%. Drying began in the late afternoon, and continued through the night and into the

following day. The dashboard fan was powered by a battery during the night and by solar energy during the day. Because the maize was at a high initial moisture, drying occurred even during nighttime hours, because the wet maize can still transfer water to the higher humidity night time air. Although the drying rate is slower during the night when there is no solar heating of the air inside the plastic, it takes less calendar time to dry the maize. In this test, the maize was dried to 13.3% in slightly more than a day (27 hours), and the average drying rate was slightly above 0.5 percentage points per hour.

- Test #3, five larger drying trays were used 86 cm long and 51 cm wide with a depth of 8.9 cm. These trays could easily hold 90 kg of wet maize. Drying started late afternoon (16:30) and continued overnight. Drying rate averages over time were as follows
  - 0.33 percentage points/hour between 16:30 on 07/18 and10:00 on 07/19
  - 0.786 percentage points/hour between 10:00 and 17:00 on 07/19.
  - 0.12 percentage points/hour between 17:00 and 21:15 on 07/19 (maize moisture went from 14.0 to 13.5% wet basis). This last observation illustrates the difficulty encountered when trying to dry the maize when it is already at a lower moisture content. Note also that the final moisture content, 13.5% wet basis, was slightly higher than the recommended safe storage moisture of 13% humid tropics.

For the last three drying tests (#4 to #6), the dashboard fan was replaced with Apevia 120 mm Ultra Silent Case fans which utilize 12 V DC power. This type of fan is used for cooling electronic equipment and computers. Five fans were connected together by securing them to a strip of wood and used for tests #4 and #5.

- For test #4, additional wood strips were used to form a frame around the fans that was held in place with a wire. The plastic could be secured to this frame. Additionally, a wire frame was added to each of the trays to support the plastic so that it did not touch the top surface of the maize.
- For test #5 the fans were enclosed by an improved wooden frame held together by nails.
- For test #6, seven fans were used and a wooden frame was constructed to enclose them, giving a more effective sealing of the plastic around the fan's frame.

Table 5. Summary of POD tests conducted between June 20, 2017 and September 22, 2017

Test #	Date	Configuration	Start hour	Kg of wet maize	Initial MC (% w b)	Final MC (% w b)	Drying Time (hrs)	Drying Rate (pts/hr)
1	06/20	Small trays, dashboard dual fans	09:30	50	21.8	12.8	29.5	0.30
2	06/27	Small trays, dashboard dual fans	17:40	50	27.9	13.3	27.0	0.54
3	07/18	Larger trays, dashboard dual fans	16:30	90	25.2	13.5	28.75	0.41
4	08/07	Larger trays, five Silent Case Fans	17:00	90	26.3	12.2	30.6	0.46
5	09/07	Six plastic trays, five Silent Case Fans	18:05	90	27.2	13.9	29.1	0.46
6	09/15	Larger trays, seven Silent Case Fans	12:00	122.9	26.8	12.2	24.9	0.586

When five fans were used, the plastic that forms the "plenum" over the top of the drying bed was only partially "inflated." This facilitated airflow within the dryer. The frame was formed by nailing a small strip of wood, approximately 0.6 cm thick, 3.8 cm wide and 15 cm long, to the center of one side of each tray so that it protruded above the top of the tray about 10 cm. A strong wire was secured to each end of the tray and positioned in a shallow notch in the center of the top of the wood piece to form a triangular frame as seen in Figure 7.

- Test #4, which began at 17:00 on 08/07 with re-wetted maize at 26.3% mc, the fans were run continuously until 21:00 on 08/08, at which time the maize had dried to about 14.5% mc. The fans were shut off overnight and restarted at 12:30 on 08/09 until the test was terminated at 15:45. The average moisture content of the maize on the five trays was 12.9%. As shown in Table 5, the average drying rate was 0.46 percentage points per hour.

- Test #5 used the plastic drying trays that Klein Ileleji has developed for drying maize and other products in Africa (see Figure 9). The trays were smaller than the wooden trays used for tests #3 and #4, thus six trays were used to attain the 90 kg capacity. The sides of the tray were shallower in the middle than on the corners. This limited the capacity of the tray and would have made it more difficult to secure the plastic to the sides of the trays. Wooden inserts were fashioned to fit into these depressions or notches, giving the trays a depth of over 10 cm. Pieces were also inserted in the "notches" on the longer sides of the trays on both ends of the assembled dryer so that the wooden frame with the five fans could be attached to one end of the assembled dryer and the plastic sheet could be more easily secured around that end of the dryer. Drying started at 18:05 on 09/07 and drying continued until 09/08 at 18:30. The fans were turned off and final samples for the day were taken from each tray. The average moisture was 16.1%. Fans were restarted at 10:40 on 09/08 and drying continued until 16:30 when the average moisture content of the maize on the 6 trays was 12.9%. One observation of this test was that relative humidity reached 100% at 24:00 on 09/07 and remained at 100% until 09:00 on 09/08. The maize moisture dropped from 27.2% wb to 25.1% wb at 8:45 am on 09/08, giving a drying rate of only 0.16 percentage points per hour. This illustrates the importance of running the fans only when drying can be achieved. Less battery power would have been consumed if the fans had been stopped between 11 pm on 09/07 and 9 am on 09/08.
- Test #6, used maize harvested by hand from a field at Purdue's Agronomy Center for Research and Extension (ACRE). It was shelled using a rubber roller sheller available at Purdue's Plant Phenotyping Facility at ACRE. Ears were harvested Thursday evening 09/14 and shelled the morning of 09/15. Approximately 118 kg, was placed on a plastic tarp in the sun for drying and122.9 kg were placed in the 5 wooden trays of the POD (Figure 7).

Figure 7. POD with shelled maize in its trays (left) prior to addition of the plastic covering and (right) POD covered with plastic along with shelled maize drying on the tarp (rear). In the picture on the left, the seven fans enclosed in a frame can be seen on the tarp in front of the first POD tray.

The tarp test started at 11:30 on 9/15 and the POD test began less than an hour later, at 12:20. Drying continued through 20:30 on 09/15 at which time the POD fans were stopped and the maize on the tarp was collected and placed in a plastic garbage can and moved inside the ADM building. The POD dryer remained outside the building. Drying was resumed on 09/16 at 09:30 and continued through 18:30. At this point the average moistures of the maize on the tarp and in the POD were 16.9% and 14.9%, respectively. Rainy weather was predicted for the next several days, so drying was stopped and resumed on 9/21 at 9:30 (Tarp) and 10:15 (POD). Drying stopped at 19:00 (Tarp) and 19:15 (POD). The POD maize had an average moisture of 12.2% mc and the maize on the tarp was at 14.5% mc. Therefore, the maize from the tarp drying tests was again placed on the tarp on 09/22 between 10:15 to 16:40. Final moisture of the maize on the tarp was 12.5%.

Figure 8 is a plot of the moisture contents of the shelled maize in each of the trays in test #6 at the times samples were taken. The horizontal axis shows hours of drying only. It excludes times when the maize was not on the tarp and the POD fans were not running. The vertical axis show the approximate location of breaks where the drying was stopped overnight. Those points were nearly the same at the end of the first day of drying (September 15) because the tarp test was started and terminated earlier so that the number of drying hours was nearly the same. However, at the end of the second day there was a difference in number of hours of drying because the samples were taken at different times. For the POD test the moisture contents of the samples converge at the transition from September 16-17 because the maize was removed from the trays and mixed as it was placed in a plastic can for storage until the weather allowed the tests to be resumed. The maize equilibrated so that moistures of samples taken from each of trays were nearly identical when the test was resumed on September 21. The moisture content of the maize on the tarp appeared to rise slightly between September 16 and 21because of sampling variability. The moisture contents at the end of the day on the 16th and the beginning of the 21st were determined by averaging moistures of three samples taken from three different areas of the tarp. The lines for tray 4 are dashed between hours 8.5 and 15.9 because the investigators suspect that the sample labels were exchanged when the moisture meter was being used to quickly determine the approximate moisture contents of the samples soon after the samples were taken. Therefore, the samples moisture contents were switched so that the drying curve showed a steady decline in moisture that was similar to the decline observed for the other trays.

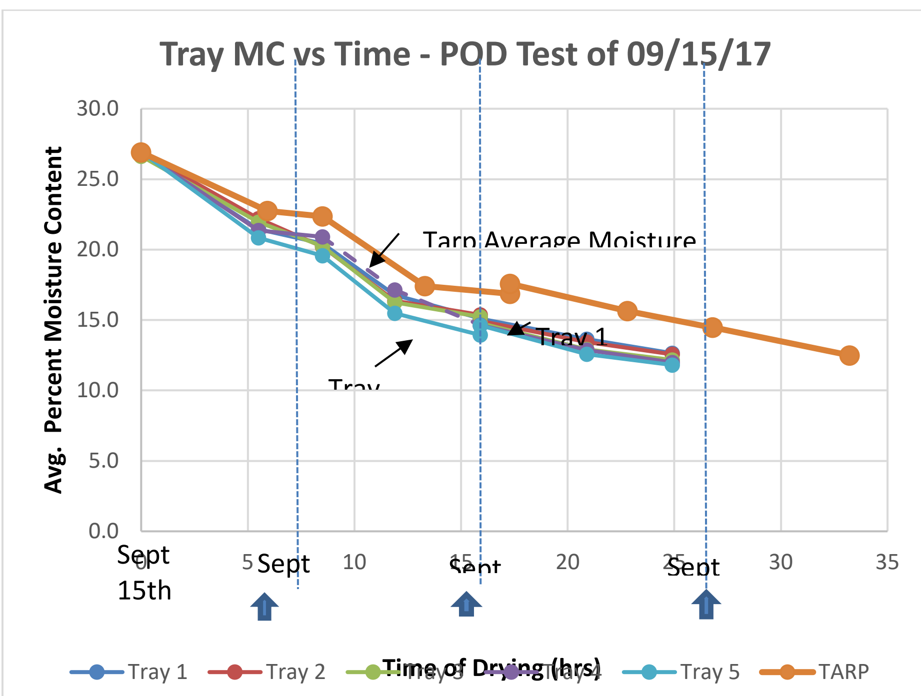


Figure 8. Moisture contents of maize in POD dryer trays and tarp for various drying times; test #6 (09/15/2017)

Figure 8 shows that drying was fastest for both the POD dryer and the tarp during the initial period of drying when the maize moisture contents were high and air conditions were excellent for drying (low RH and elevated temperatures). Drying rate slowed considerably when moisture contents were below 16%. The moisture on the POD trays was not uniform. This may have been caused by differences in drying air temperature. Solar heating during the middle of the day increased the temperature on the surface of the tray by 0°C to 8.5°C. For measurements taken early or late in the day, the maize inside the dryer was below ambient, presumably because the air temperature dropped slightly as a result of evaporative cooling. The temperatures on the maize surface for tray 1 (closest to the fan) and tray 5 (furthest from the fans) varied. In the morning through afternoon, the temperature on the surface of the maize in tray 5 was between 2.0 and 4.5 °C higher than the temperature on the surface of the maize in tray 1. Tray 1 was near the fan and there was little time for solar heating of this air before it was pushed through the bed of shelled maize whereas in tray 5 the air had traveled the length of the dryer and had more time to be heated by the solar radiation being trapped by the plastic. Near the end of the day when the angle of the sun was such that the end of the dryer near the fans received more solar radiation, the temperatures on trays 1 and 5 were nearly the same. Although the moisture contents of maize from the trays varied by 1 to 2% before the maize reached 15% mc, the moisture contents of the maize in the trays at the time of the final sampling only varied by about 0.8%. The wetter maize tended to "catch up" to the dryer maize during the last few hours of drying.

Next steps:

Although the investigators feel there are improvements that could be made to enhance the performance of the POD, it has been developed to the point that it can be tested by KALRO and farmers working with KALRO. Therefore, they are currently designing plastic trays that will replace the wooden trays. Once the plastic molds have been produced, the cost per tray will be approximately $2.50 and the cost for a fan holder and other plastic components will be similar. If six trays were used to form the dryer, the cost of the dryer and fan frame would be approximately $20. The retail cost of the fan, solar panel, and battery, charge controller, plastic sheeting and small components such as clips to fasten the plastic sheets to the plastic trays, will add another $100. If the dryers were mass produced, the cost of the injection molds for the plastic components, which could be about $8,000, would have to be distributed over the cost of the dryers produced. However, this would reduce the cost of the trays to under $1.00. If hundreds of the dryers were built, the cost of the solar panel ($45) and battery ($18) would probably drop by about 25%. Therefore, it should be possible to sell the dryer for around $100, which is the target price for the dryer identified by "willingness to pay" studies conducted by project personnel in previous years.

The investigators are currently discussing these designs with a company that can produce the plastic molded components. They hope to have trays available for testing at Purdue in mid to late December. This should permit prototypes to be sent to Kenya in time for testing during the March maize harvest.

1.3.2 - Complete modeling effort for solar cabinet dryer and validate with field data: solar dryer control for optimum performance

No load tests were carried out on the multipurpose solar dryer (Figure 9) without crop inside the drying chamber in order to determine how the dryer operated under various fan cycle operations. The maximum stagnation temperature in the drying chamber and the overall heat loss coefficient were determined (see Table 6). Having all the fans running at the same time not only reduces the available amp hours to run the fans, but also decreases the chamber temperature due to increase in overall heat loss coefficient (54.84). Also, having just the two front fans running increased the heat loss coefficient more than when the six bottom fans were running (50.78 compared to 24.83). It therefore appears that having a smart control system to conserve battery power and optimize chamber temperature by operating the fans of the solar dryer efficiently needs to be implemented. Therefore, a smart control console will be implemented in the final design concept.

Figure 9. The Multipurpose solar dryer

Table 6 No-load test for different fan configurations

Dryer mode	Drying time (hrs)	Solar radiation intensity, I (kWh/m^2)	Max. stagnation temp., T_s (°C)	Ambient temp., T_a (°C)	Overall heat loss coefficient (U_L)
All fans OFF; b.f. sealed	10	5.28	52	28.3	18.01
Only front fans ON; b.f. sealed	8	4.85	35.3	25.6	50.75
Only bottom fans ON; b.f. sealed	8	5.76	54.6	31.1	24.83
All fans OFF; b.f. unsealed	6	4.48	43.1	26.7	36.92
Only front fans ON; b.f. unsealed	5	6.02	46.3	28.3	54.14
Only bottom fans ON; b.f. unsealed	8	6.45	42.7	27.2	42.08
Front and bottom fans ON; b.f. sealed	7	5.95	41.4	28.9	54.84

The thermal efficiency and specific energy consumption were determined for the measured field data obtained for the multipurpose solar dryer. The solar dryer was configured manually to operate fans under three different modes (fan run cycles) indicated on tables 2 to 5 as modes 1, 2 and 3. Also, tests were conducted using wet corn loaded unto the tray full (9 kg), half (4.5 kg) and a thin layer. The wet corn was dried to 13.5%. The thermal efficiency, defined as the thermal energy utilized for drying, divided by the thermal energy available for drying, was determined. The specific energy consumption, defined as the solar energy required for the removal of one kg moisture from the product, was also determined. Both values are shown in Tables 7 to 10 for field drying tests conducted in West Lafayette, Indiana, USA, Kakamega, Kenya and Velingara, Senegal. The modes of operation affected the thermal efficiencies and specific heat in all three locations, showing the need to implement a smart control to effectively capture the thermal load available.

It should first be noted that the performance of solar dryers is very weather/location specific and results need to reflect on the local weather conditions that may have affected performance. In general, Velingara, Senegal was hotter and less humid than Kakamega, Kenya and West Lafayette, USA. Thermal efficiencies were higher on the first day of drying than on subsequent days, which was due to the ease of removing less bound moisture from the grain than tightly bound moisture as drying progresses. In general the solar dryer performed relatively well, compared to other designs available in literature. The goal in year four is to implement a more efficient thermal capture, smart control console, test more durable parts, and work on prototyping toward commercial manufacture.

Table 7. Daily thermal efficiency for dryer modes of operation at West Lafayette

Dryer mode/load		Thermal efficiency (η), %					
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
	Mode 1	38.60	17.89	5.35			
Half load	Mode 2	46.99	31.65	18.16			
	Mode 3	47.54	13.26				
Full load	Mode 1	22.99	17.38	7.31			
	Mode 2	65.06	30.07	33.56	19.85	14.79	5.52
	Mode 1	14.30	8.76	4.67			
Thin layer	Mode 2	20.77					
	Mode 3	10.40	12.02				

Table 8. Daily specific energy consumption for dryer modes of operation at West Lafayette

Dryer mode/load		Specific energy consumption (MJ/kg)					
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
	Mode 1	0.58	1.26	4.22			
Half load	Mode 2	0.48	0.71	1.24			
	Mode 3	0.47	1.70				
Full load	Mode 1	0.98	1.30	3.09			
	Mode 2	0.35	0.75	0.67	1.14	1.53	4.09
	Mode 1	1.58	2.58	4.83			
Thin layer	Mode 2	1.09					
	Mode 3	2.17	1.88				

Table 9. Daily thermal efficiency and specific energy consumption for dryer modes of operation at Kakamega, Kenya

		Thermal efficiency (η), %								
Dryer mode/load		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Half load	Mode 1	50.19	8.61	4.18	1.89	3.4	2.39			
Full load	Mode 1	31.23	17.56	N/A	18.18	11.08	14.58	8.4	15.4	1.53

		Specific energy consumption (MJ/kg)								
Dryer mode/load		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Half load	Mode 1	0.45	2.62	5.40	11.9	6.64	9.41			
Full load	Mode 1	0.72	1.29	N/A	1.24	2.04	1.55	2.69	1.47	14.78

Table 10. Daily thermal efficiency and specific energy consumption for dryer modes of operation at Velingara, Senegal

		Thermal efficiency (η), %			Specific energy consumption (MJ/kg)		
Dryer mode/load		Day 1	Day 2	Day 3	Day 1	Day 2	Day 3
Half load	Mode 2	33.27	26.46	21.58	0.68	0.85	1.05
Full load	Mode 2	65.46	58.04	42.54	0.34	0.39	0.53

Capacity Building

Ravindra Shrestha graduated in May 2017 with an MS in Agricultural and Biological Engineering and returned to his home country, Nepal. He is currently working on a CIMMYT project in Nepal related to crop post-harvest.

Presentations and Publications:

1. Shrestha, R. 2017. Development and testing of a multipurpose solar dryer for smallholder farmers-corn (*Zea mais*) drying. M.S. Thesis.
2. Shrestha, R. K.E. Ileleji and C.P. Woloshuk. 2017. Survey of smallholder farmers' postharvest practices in Kenya and Senegal; in preparation.
3. Lowenberg-DeBoer, J. Designing Affordable Grain Dryers for On-Farm Use in Africa. Presented at the Post-harvest Congress in Nairobi, Kenya, March, 2017.

<u>Activity 1.5 - Determine impact of grain moisture on aflatoxin accumulation in hermetic bags</u>

i. Description: To better understand aflatoxin development in hermetic bags in Senegal.
ii. Location: Velingara, Senegal
iii. Collaborators[5]: Ibrahima Sarr, Moussa Kande, and Boubacar Balde
iv. Achievements:

Maize stored at 18% in hermetic containers (PICS and impregnated A-Z bags) or regular woven bags for 3 months and sampled periodically for moisture and aflatoxin accumulation. After one month, the moisture content dropped by 2% in hermetic bag and 6% in women bags reaching 16% and 12% respectively. At the same time, aflatoxin accumulated in both bags but much more in woven bags (Figure 10).

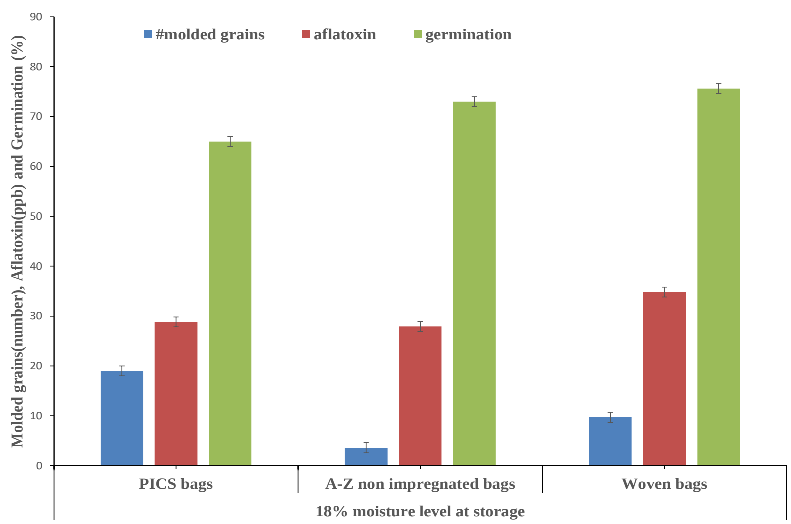


Figure 10. Contamination and quality of maize at 18% moisture content after one month storage in hermetic bags in Velingara (Senegal).

The experiment was repeated for maize stored at 13%. The moisture content drop was slower and smaller with 1% in the hermetic bags and 2% in woven bags. The hermetic bags showed more efficacy preserving the grain quality in particular with impregnated A-Z bags where no insects were found. Additionally, aflatoxin accumulated more in woven bag but no significant difference was noted in both hermetic bags (Figure 11).

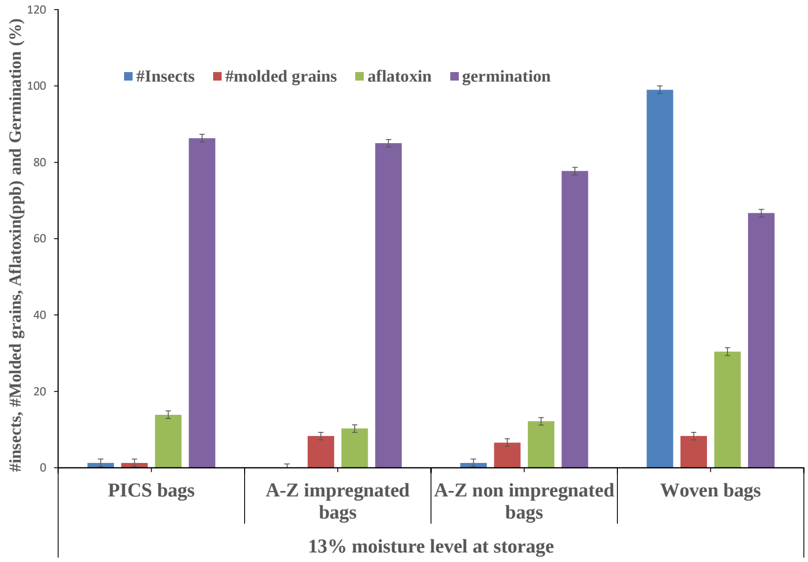


Figure 11. Contamination, infestation and quality of maize at 13% moisture content after three months of storage in hermetic bags in Velingara (Senegal).

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

PROJECT 1

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 and Mario Ferruzzi (Purdue); Violet Mugalavai & Augostino Onkware (University of Eldoret, Kenya); Djibril Traore (ITA, Senegal); John Taylor & Gyebi Duodu (University of Pretoria); Hugo DeGroote (CIMMYT, Kenya)

iv. Achievements:

KENYA

(a) University of Eldoret:

Activity 2.1.1: In-home use study

As an extension of the willingness-to-pay (WTP) study done in the summer of 2016, an "in-home use" study was initiated in this project period (July 2017). The objective was to understand how consumers react to instant flours when they use them in the home. Instant flours of maize, and blends of maize and sorghum prepared at the Incubation Center were used in the study. Five formulations were used (Table 11). A pre-study done by Purdue PhD student, Emmanuel Ayua, showed that consumers appreciate blends of maize and sorghum, though as sorghum proportion increases to a high level, sensory attributes of the thick porridge (ugali) decrease even though appearance is judged high. This suggests that consumers judge sorghum incorporation very positively despite its comparatively poorer taste and texture (Figure 12).

The study was conducted in a four gated communities (Estates) targeting households with children. Seventy-seven households were randomly selected and each received five different flour samples, 200 g each. The respondents were given demonstrations on how to prepare thin (Uji) and thick/stiff (Ugali) porridges. Each participants received the five flour samples and a questionnaire, which were collected after three weeks.

Table11. Codes for samples used in the in-home study in Eldoret, Kenya

Samples Code	Ingredients	Percent /100g
NHI4	Maize	**25**
	Sorghum	**25**
	Amaranth	**20**
	Baobab	**15**
	OFSP	**15**
LU29	Maize	**35**
	Sorghum	**15**
	Amaranth	**20**
	Baobab	**15**
	OFSP	**15**
VJ34	Sorghum	**35**
	Maize	**15**
	Amaranth	**20**
	Baobab	**15**
	OFSP	**15**
RS46	Maize	**50**
	Amaranth	**20**
	Baobab	**15**
	OFSP	**15**
WB57	Sorghum	**50**
	Amaranth	**20**
	Baobab	**15**
	OFSP	**15**

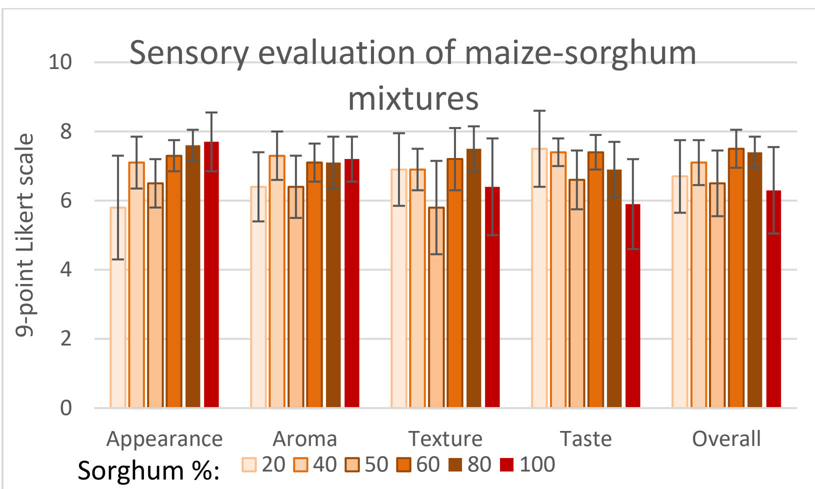


Figure 12. Consumer liking of ugali with increasing levels of sorghum mixed with maize.

All composite flour formulations received high consumer acceptability scores for thin porridges (Table 12) compared to thick/stiff porridges (Table 13). There was need to adjust the formulation of the flour for thick/stiff porridge (ugali) to increase acceptability. The reason given for low acceptability was the sour taste, which is not characteristic to thick/stiff porridges but normal for thin porridges.

Table 12. Likeability Responses for Thin Porridge (Uji)

Variables	Sample Codes (see below) and % responses				
	WB57	RS46	VJ34	LU29	NH14
Appearance	67	76	83	82	82
Texture in hand	77	78	79	78	79
Aroma	82	65	86	70	80
Texture in mouth	72	78	76	83	72
Taste	73	69	69	78	75
General acceptability	85	76	77	82	79

N=77

NB: The responses of those who rated the product as "like" and "like very much" have been collapsed and compounded to get the total percentage response of the positive likeability of the product.

Table 13. Likeability Responses for Stiff Porridge (Ugali)

Variables	Sample Codes (see below) and % Responses				
	WB57	RS46	VJ34	LU29	NH14
Appearance	69	59	40	57	50
Texture in hand	60	59	53	65	57
Aroma	52	48	49	43	64
Texture in mouth	52	60	49	61	52
Taste	30	56	47	44	43
General acceptability	49	54	47	51	41

N=77

Note: RS46 which was fortified maize and LU29 which had more maize than sorghum, were the most preferred for stiff porridge (Ugali).

(b) CIMMYT:

Activity 2.1.2: Consumer study in Touba, Senegal

Data analysis for the study of March 2016 (previously presented at the AAAE conference in Addis Ababa, Sept. 2016) was finalized. The results showed that there is a potential market in Senegal for instant and fortified cereal food products, but likely in the higher income and education groups. The increase in cost needs to be compared to the premiums consumers are willing to pay. The next step is to test the new and promising products in pilot markets, with target consumers.

Activity 2.1.3: Acceptance and willingness to pay (WTP) for fortified products in Eldoret, Kenya

Data analysis for this study (conducted in July 2016 and reported in previous reporting cycle) has been completed and a manuscript is being prepared. The results (Figure 13) showed consumers' willingness to pay a premium for mixed flours (27%), for instant flour 19%), and for fortification (25%), after receiving information about products. The conclusion is that there is a potential market in Kenya for instant cereal food products. However, the natural fortificants used need to be carefully selected, and their performance and costs compared to artificial micronutrient premixes. The increase in cost needs to be compared to the premiums consumers are willing to pay.

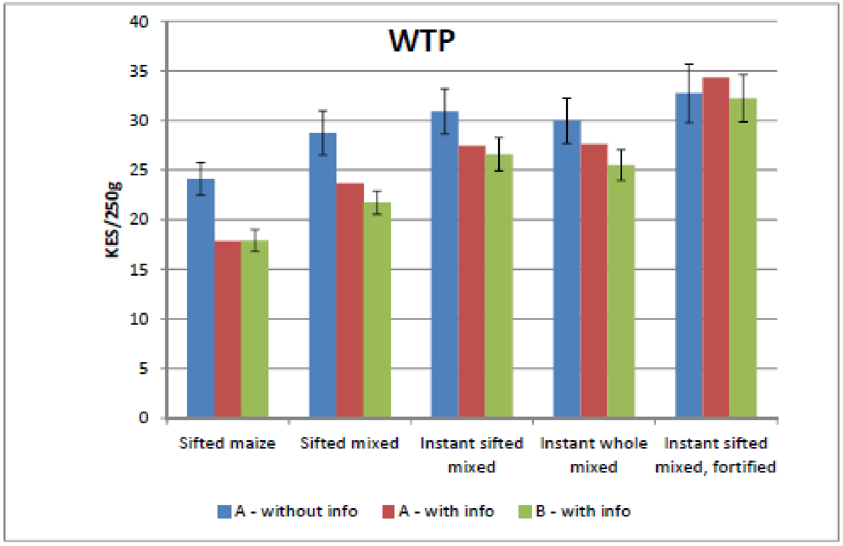


Figure 13. Willingness to pay for different cereal products in Eldoret, Kenya

Activity 2.1.4: Consumer study on acceptance and willingness to pay for instant fortified millet products in Dakar, Senegal.

The study was conducted in March 2017, with 300 consumers drawn from the suburbs of Dakar (Guediawaye, Thiaroye, Pikine, Derkle, Geule Tapee, Ouagou Niaye). Five products were evaluated: 1) sifted millet flour, 2) instant sifted millet flour; 3) instant whole millet flour, 4) instant whole millet flour fortified with micronutrients, 5) instant whole millet flour fortified with micronutrients, carrots and bouye (Figure 14). Study data is being analyzed.


Figure 14. Preparation of samples for a sensory study in Dakar, Senegal

SENEGAL

Institut de Technologie Alimentaire (ITA):

Activity 2.1.5: Investigating nutrient-rich value chains for fortification in Senegal

ITA was involved in investigating locally available nutrient-rich value chains (i.e., baobab fruit flour/bouye, moringa leaves, papaya, mangoes, cowpea and peanut) for enhancement of the nutritional value of processed products from local cereals (millet, sorghum and maize). Weaning food were developed using the local crops (millet, cowpea, peanut butter) and the nutrient-rich crops (baobab flour – bouye and carrots) as well as vitamin and mineral mixes. These products have been optimized at ITA and are ready for transfer to processors.

SOUTH AFRICA

University of Pretoria:

Activity 2.1.6: Sensory quality of products

In support of the FPL's naturally fortified porridge product development activities, the effects of decortication of pearl millet grain and of extrusion cooking on the shelf-life of pearl millet-based instant porridge flour is being evaluated by sensory evaluation at the University of Pretoria. This is being done using the "Survival Analysis" technique, which involves the analysis of time-to-event data. Such data describe the length of time from an origin to an endpoint of interest. The event of interest in this study is the onset of rancidity in flours in storage at different temperatures, and the endpoint is desired shelf-life of the flour product (Figure 15). Flours were stored for up to 6 months at different temperatures to simulate actual product storage at retail and in the home. The work is being conducted by PhD student Isiguzoro Onyeoziri under the supervision of Profs Riette de Kock and John Taylor.

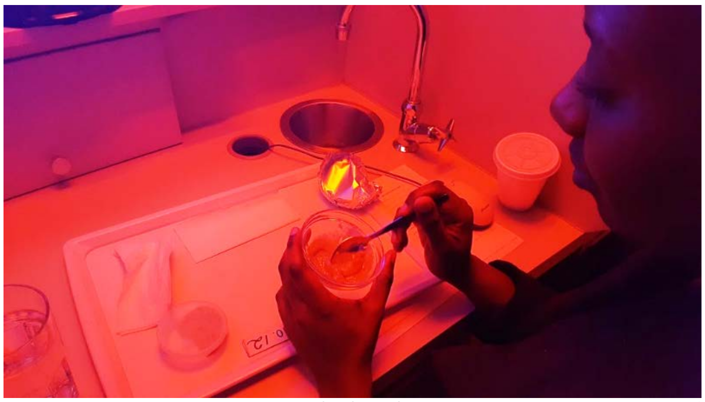


Figure 15. Testing the shelf-life of extruded product using "Survival Analysis" technique

UNITED STATES

Purdue University:

Activity 2.1.7. Impact of extrusion on lipid oxidation and acceptability of whole grain pearl millet (Pennisetum glaucum) flours.

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

Activity 2.1.8. Effect of extrusion at different moisture conditions on starch gelatinization and physico-chemical properties of pearl millet flours.

Objectives: Extrusion technology is widely used for the manufacture of various snack and other foods at varied conditions. In the field, conditions must be set for economical use of the extruders. The lowest possible moisture conditions for complete gelatinization of starch during extrusion cooking is an important parameter for energy consumption of the extruder and a dryer is needed to dry extrudates prior to milling to instant flours. Such information is needed for entrepreneurs to optimize extrusion process for greater profit. The effect of extrusion was assessed at different moisture conditions on starch gelatinization and pasting properties of pearl millet.

Methods

Sorghum was milled into grits and the moisture content adjusted to 27, 29, 31, 33 and 35% wet basis. Samples were then packed in Ziploc bags and equilibrated overnight in a cold room. On the experimental day, the samples were removed from the cold room and allowed to equilibrate at room temperature, followed by verification of moisture content using a hot air oven. After extrusion, the extrudates were dried in 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, as viscosity is needed in instant flours. Rheometry was used to assess the viscoelastic properties of the extrudates.

Results

- 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 (Figure 16).
- Extrusion between 27-35% moisture conditions all completely gelatinized the starch, although the energy used was higher due to greater friction caused by the feed.
- Storage moduli was greater than loss moduli for the lower moisture extrudates, indicating the formation of more elastic extrudates.

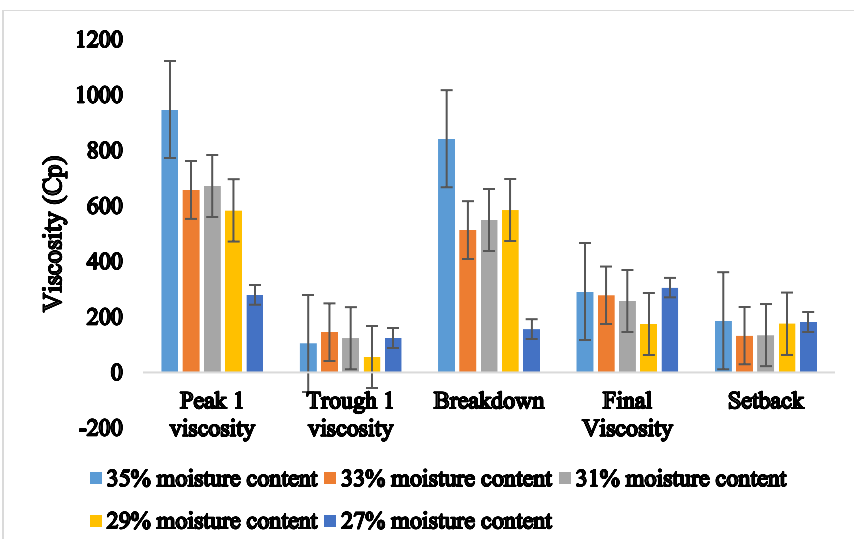


Figure 16. Viscosities of instant flours extruded at different moisture conditions. Peak viscosity was high for instant flours extruded at 35% moisture conditions. Final and setback viscosities were not statistically different in the flours.

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 data using size exclusion chromatography.

v. Capacity Building:

1. Trainings and demonstrations: The University of Eldoret Incubation Center was active over the 12-month period. The team trained 41 processors (females – 29; male –12) on extrusion and other processing methods (Figure 17). An additional 16 women cereal processors were trained at the Incubation Center in collaboration with SMART FOODS PROJECT of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The Eldoret researchers participated in three exhibitions and conducted demonstrations to the public on how to make thin and thick porridges using the instant flours. During the Annual Agribusiness Trade Fair held at University of Eldoret, 1000 participants attended the demonstrations on how to make thin and thick porridges using the instant composite cereal. Consumers have expressed high interest in the instant cereal products.
2. In Senegal, the processing unit of Mme. Mbacke was upgraded to meet hygienic standards for processing of fortified instant millet flours.
3. Student study supported noted in the long-term training table under "human and institutional capacity development".

Figure 17. Participants in the training session at University of Eldoret Incubation Center

vi. Lessons Learned:

1. Interest in the incubation centers in Kenya and Senegal is high and growing. At University of Eldoret, the Center is now fully functional serving the purpose of training prospective entrepreneurs as well as university students in small business development. CGIAR Nairobi offices of CIP and ICRISAT have visited the Incubation Center, which has led to initiation of activities, including an R&D function on orange-fleshed sweet potato. In Senegal, meetings have been held with government officials on a joint activity that will expand Mme. Mbacke's processing facility in Touba and initiate extrusion processing of fortified food products in two other areas of the country. The office of Cellule de Lutte contre la Malnutrition (CLM), Programme de Renforcement de la Nutrition, which leads programs directed at decreasing malnutrition in Sénégal, has placed orders for instant fortified millet flours.
2. Nutritionally fortified instant millet flours are accepted by consumers and studies in Senegal and Kenya show willingness to pay more for them. In Kenya, the better market for instant flours was shown for thin rather than thick porridge.
3. In both Kenya and Senegal, discussions are underway with potential funding partners, on scaling-up activities to expand rural processing of fortified instant foods. In Kenya, we have a pending proposal on adding of another Incubation Center in a different value-chain.

vii. Publications and Presentations

1. DeGroote, H., Kariuki, S.W., Traore, D., Taylor, J.R.N., Ferruzzi, M., Hamaker, B.R. 2017. Measuring consumers' interest in instant fortified pearl millet products: A field experiment in Touba, Senegal. Journal of the Science of Food and Agriculture, online: doi:10.1002/jsfa.8722.
2. Torres-Aguilar, P., Martínez, M.M., Hamaker, B.R. Impact of low-cost extrusion on lipid oxidation and acceptability of whole grain pearl millet (Pennisetum glaucum) flours. Institute of Food Technologists annual meeting, Las Vegas, NV, June 2017
3. Technology-based Incubation Centres for Developing Affordable Nutritious Foods Mugalavai, V., Onkware, A., Ferruzzi M.G., Debelo, H., Ndiaye, C., Traore, D., De Groote, H., Taylor, J.R.N., Duodu, G., Bugusu, B., and Hamaker, B.R. Presented at the Post-harvest Congress, Nairobi, Kenya, March, 2017.
4. FPL participated in an exhibition at the Integrated Nutrition Conference organized by Catholic Relief Services in Nairobi, in November, 2016. Dr. Mugalavai interacted with consumers and did demonstrations on how to make instant thick and thin porridges.
5. The "Small Scale Food Processing Manual" was updated to include a "Business" section to equip the trainees with knowledge and skills for business improvement and start-ups.

PROJECT II:

i. Name: Nutritional studies

ii. Description: Screening of nutrient-rich plant materials for use in consumer based food products in Senegal and Kenya.

iii. Location: Purdue, USA, Dakar and Touba, Senegal, and Eldoret and Nairobi, Kenya

iv. Collaborators[5]: Mario Ferruzzi - lead (Purdue); (Violet Mugalavai & Augostino Onkware (University of Eldoret, Kenya); Djibril Traore (ITA, Senegal); Johanita Kruger (University of Pretoria, South Africa).

v. Achievements:

(a) Purdue University:

Activity 2.1.9: Development of extruded naturally-fortified (cereal/nutrient-rich plants) blends

Progress has been made in the translation of formulas from previous year (2015/16) toward the development of extruded blends of cereals and nutrient dense plant materials for application to Senegal and Kenya (Figure 18). In this project period (Year three), blends of whole grain pearl millet with nutrient dense plant powdered ingredients including solar dried carrot, *Adansonia digitata* (baobab), or *Moringa oleifera* (moringa) were adjusted to ~35% moisture prior to extrusion using a Technochem Mini-Extruder© (speed fixed at 900 rpm; final temperatures ranging between 105-121 °C) with a barrel diameter and L/D ratio 276 mm and 5:1, respectively. Solar dried carrot (CRT, *Daucus carota*) powders were obtained after drying fresh sliced carrots using a solar dryer developed by the storage and drying team of the FPL project (patented PCT/US16/46803, licensed by Jua Technologies International, IN, USA). This technology developed for grain drying has been adapted through this project to produce high quality dried fruit and vegetable powdered products in limited batch sizes suitable for production of blended fortified food products.

Formulations as anticipated, were found to significantly impact final color and quality attributes as well as nutritional content including provitamin A and iron content (previously described). Total color variation was most apparent in formulations with carrot but also with addition of baobab which had a lightening and subtle yellowing effect on the final product as assessed by Hunter LAB. Extruded WG millet with baobab (5%) lightened the final product compared to WG extrudate; while co-extruded WG millet with CRT enhanced browning index and Chroma values ($p<0.05$). Total variation is depicted in Figure 19.

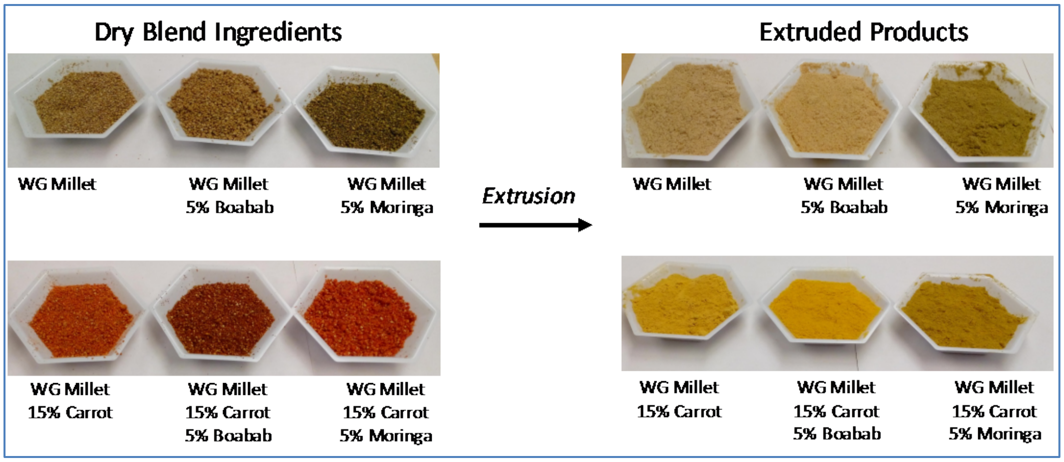


Figure 18. Blended millet products formulated with nutrient dense ingredients before and after extrusion processing.

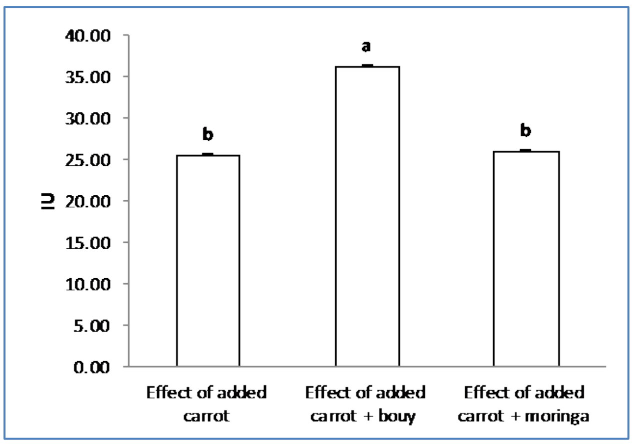


Figure 19. Effect of added nutrient dense plant materials on total color variation.

Carrot provitamin A stability was observed to be high through extrusion with average recoveries of 60 to 90.34% depending on specific co-formulation factors (Figure 20). Findings suggest stabilization of carotenoids in extruded blends containing baobab and moringa relative to simple carrot millet blends.

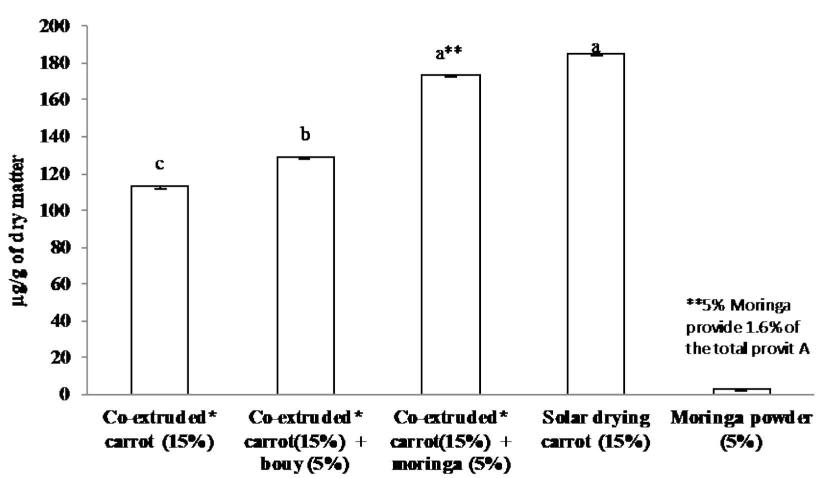


Figure 20. Provitamin A levels in starting carrot and moringa ingredients (per formulation level and after extrusion of blends.

Stabilization of carotenoids by baobab and moringa are being explored in relation to their phenolic and ascorbic acid content (on-going). However, amylose and amylopectin size and starch in vitro digestibility did not change significantly with inclusion of carrot, moringa, and baobab in WG extrudates. On the other hand, extrusion of blends appear to have resulted in the complexation of carotenoids with amylose (with lower enthalpies in WG-carrot and WG-carrot-moringa), which may provide a basis for carotenoid stabilization through extrusion. These factors will be explored further in Year 4 as the products are translated to market in Senegal and Kenya.

(b) University of Pretoria:

Activity 2.2.1: Natural fortification with moringa leaves and baobab fruit pulp

In support of the project activities in Senegal and Kenya to improve the micronutrient nutritional quality of the cereal-based instant porridge products, the effects of adding 5% and 15% dried moringa leaves(M) and baobab fruit pulp (B) to instant whole pearl millet instant porridges on iron and zinc bioaccessibilities (in vitro dialysability) was determined (Figure 21). The work was carried out by MSc student Renee van der Merwe under the supervision of Dr. Kruger and Prof. Taylor.

Despite the high iron content of the moringa (58 mg/100 g, db) its addition to the pearl millet-based porridge was the least promising with respect to increasing the iron and zinc bioaccessibility. Its addition at 5% resulted in slightly lower improvements in iron and zinc bioaccessibility compared to baobab (5%) and at 15%, iron bioaccessibility was decreased and zinc bioaccessibility was similar to that of the pearl millet-based porridge. In contrast, addition of baobab at 15% had a much larger positive effect, with substantial percent increases (compared to pearl millet-based porridge) in the percentage and amount of bioaccessible iron (129 and 154%, respectively) and zinc (225 and 181%, respectively).

The findings from this research strongly indicate that baobab fruit has the potential to substantially improve iron and zinc bioavailability in cereal-based foods. This is probably due the high contents of ascorbic acid and fruit acids like citric acid in baobab fruit. This hypothesis is now being intensively investigated.

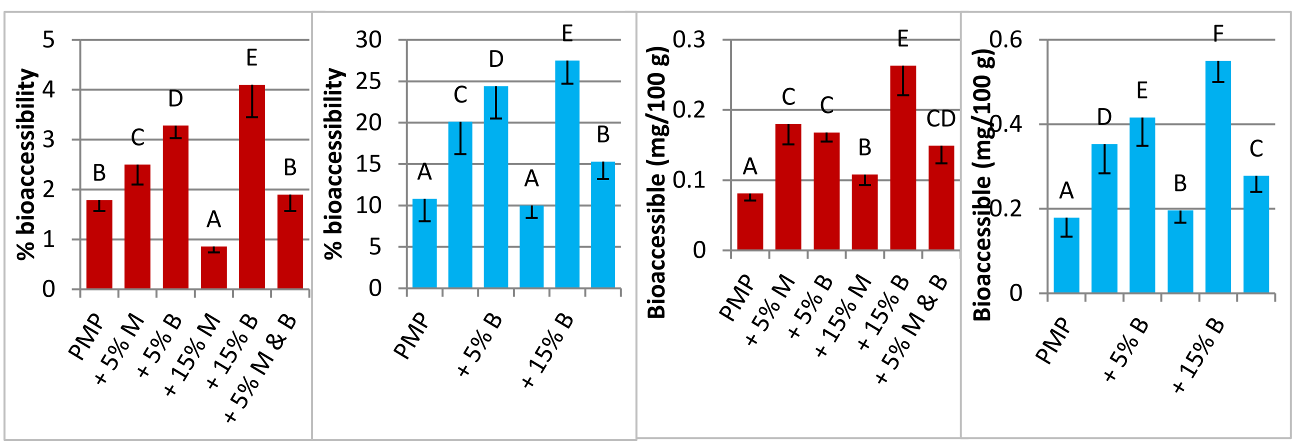


Figure 21. Effects of addition of moringa and boabab to a pearl millet-based porridge (PMP) (30% provitamin A source added) at 5 and 15% on the percentage (%) and amount (mg/100 g) of bioaccessible iron and zinc

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

Activity 2.2.2: Natural fortification with grain amaranth

In support of project activities in Kenya to improve the micronutrient and protein nutritional quality of cereal-based porridge products, the effects of different methods of souring on phytate (mineral absorption inhibitor) content and the bioaccessible Fe and Zn contents of porridges were investigated. The souring methods used were: traditional "sourdough-type" fermentation involving inoculation by back-slopping; inoculation with an indicative prebiotic Lactobacillus plantarum culture; and acidification using commercial lactic acid. Porridges were prepared using sorghum, amaranth grain, and sorghum-amaranth grain composite flours (Table 14). The work was carried out by PhD student Adeyemi Adeyanju under the supervision of Prof. Duodu, Prof. Taylor, and Dr. Kruger.

Overall, all the three methods of souring substantially reduced phytate content and increased bioaccessible Fe and Zn in the porridges. Thus, depending on the desired application, either traditional sourdough type fermentation, inoculation with a fermentative probiotic type bacteria culture or simple acidification with lactic acid will be equally highly effective in improving iron and zinc bioavailability in cereal- and the protein-rich pseudocereal porridges.

Table 14, Effect of lactic acid fermentation and lactic acid (LA) acidification on phytate content and dialysability of Fe and Zn of porridges prepared from sorghum, amaranth and sorghum-amaranth composite flours

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

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

v. Capacity Building: Students supported are noted in the long-term training table under "human and institutional capacity development".

vi. Lessons Learned:

1. Surprisingly high increases in in vitro bioaccessibility of iron and zinc were observed when baobab was added to whole grain instant millet porridges. Thus, there is the promise of increased bioavailability of these critical micronutrients. Plans are underway to test this in an acute human study in early 2018. This finding could have broad implications for delivery of these minerals in other foods.

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

vii. Publications and Presentations:

1. Kruger, J. (2016). Replacing electrolytic iron in a fortification-mix with NaFeEDTA increases both iron and zinc availabilities in traditional African maize porridges. Food Chemistry, 205, 9-13.
2. Van der Merwe, R., Taylor, J.R.N. and Kruger, J. (2017). Mineral-rich plant foods has the potential to increase iron and zinc bioavailability from an instant cereal-based porridge. 3rd Hidden Hunger Conference. Stuttgart, Germany. March 2017.
3. Leveraging Native Nutrient Dense Plants in Development of Market-led Instant Fortified Grain Foods. Ferruzzi M.G, Debelo, H., Ndiaye C., De Groote, H., Traore, D., Taylor, J.R.N., and Bugusu, B., and Hamaker, B.R. Presented at the Catholic Relief Services' Integrated Nutrition Conference, Nairobi, Kenya, November 2016.

V) HUMAN AND INSTITUTIONAL CAPACITY DEVELOPMENT[8]

a) Short-term training

Activity 3.1: Workshop on food processing technologies

i. Description: Conduct training workshops for food processors in Kenya.
ii. Location: Eldoret, Kenya
iii. Collaborators[9]: Violet Mugalavai & Augostino Onkware (University of Eldoret, Kenya);
iv. Achievements:

Trainings and demonstrations:

The University of Eldoret Incubation Center was active over the 12-month period. The team trained 41 processors (females – 29; male –12) on extrusion and other processing method. An additional 16 female cereal processors were trained at the Incubation Center in collaboration with SMART FOODS PROJECT of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

The Eldoret researchers participated in three exhibitions and conducted demonstrations to the public on how to make thin and thick porridges using the instant flours. During the Annual Agribusiness Trade Fair held at University of Eldoret, 1000 participants attended the demonstrations on how to make thin and thick porridges using the instant composite cereal. Consumers have expressed high interest in the instant cereal products.

[8] This section is to serve as a compilation of all program training activities for the 12 month reporting period and not meant to duplicate the Capacity Building section under individual Research Project Reports.

[9] Provide institutional affiliation and country.

b) Long –term training

Name	**Sex**	**University**	**Degree**	**Major**	**Program End Date**[10] **(month/year)**	**Degree Granted** [11] **Y/N**	**Home Country**
Rose Likoko	Female	University of Eldoret	MS	Food Science	2018	No	Kenya
Harriet Nyakecho Omutimba	Female	Pwani University	PhD	Social Ethics & Gender	2018	No	Kenya
Emmanuel Ayua	Male	Purdue University	PhD	Food Science	2019	No	Kenya
Cheikh Ndiaye**	Male	Purdue University	PhD	Food Science	2018	No	Kenya
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 Science & Nutrition	2019	No	Senegal
Abdourahmane Diop	Male	University of Thiès	MS	Agricultural Economics	2017	No	Senegal
Adeoluwa Adetunji	Male	Universty of Pretoria	PhD	Food Science	2015	Yes	Nigeria
Nokuthula Vilakati	Female	University of Pretoria	PhD	Food Science	2017	No	South Africa
Ayodeji Falade	Male	University of Pretoria	PhD	Food Science	2017	No	Nigeria
Isiguzoro Onyeoziri	Male	University of Pretoria	PhD	Food Science	2018	No	Nigeria
Adeyemi Adeyanju	Male	University of Pretoria	PhD	Food Science	2017	No	Nigeria
Renee van der Merwe	Female	University of Pretoria	MS	Nutrition	2017	No	South Africa
John Lubaale**	Male	University of Pretoria	MS	Food Science	2017	No	Uganda
John Gwamba**	Male	University of Pretoria	MS	Food Science	2016	No	Botswana
Tim Tubbs	Male	Purdue University	MS	Plant Science	2016	Yes	USA
Brett Lane	Male	Purdue University	MS	Plant Science	2016	Yes	USA
Stacy McCoy	Female	Purdue University	PhD	Agricultural Economics	2019	No	USA
Pablo Cesar Torres-Aguilar	Male	Purdue University	PhD	Food Science	2018	No	Ecuador
Hawi Debelo**	Female	Purdue University	PhD	Nutrition	2018	No	Ethiopia
Ravindra Shrestha	Male	Purdue University	MS	Agric. & Biological Engineering	2017	Yes	Nepal

** Students were supported on research only

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

VI) INNOVATION TRANSFER AND SCALING PARTERSHIPS[12]

a) Commercialization of solar drying technologies: Ileleji continues to make progress towards commercializing the solar drying technologies through his start-up company, JUA Technologies International LLC.

   i. Steps taken – Notices of Allowance for trademark applications filed by JUA Technologies International on the solar drying tray as "kitchen containers, enamel baskets for dehydrating foods", solar dehydrator as a "solar powered food dehydrator" and solar dehydrator as a "solar-powered electricity generator" have been issued by the U.S. Trademark Office. The applications cleared all public opposition period without problem. The next step is to file a Statement of Use showing evidence of use using physical specimens. Also, plans are currently underway to obtain trademarks in several countries of interests (Kenya, Senegal and Nigeria)
   ii. Partnerships made: Ileleji engaged with potential parts manufacturers for the solar dryer in Africa and China.
   iii. Technologies ready to scale (prototyping for commercial manufacture): Ileleji is working through JUA Technologies International on prototyping the drying trays (5 kg wet maize per tray) for manufacturing via injection molding with a local company. The long-term goal is transitioning to a local company in several regions of Africa.
   iv. Technologies transferred N/A
   v. Technologies scaled N/A

   Next step is to identify and contact USA and multi-national businesses with interest in post-harvest

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

   i. Steps taken – In early 2017, the FPL team studied the willingness to pay for the hygrometer among farmers and trades in Kenya. The Purdue team interviewed 580 people, including 305 farmers and 284 traders, from the Kakamega district in Kenya. The mean willingness to pay for the hygrometer was US$1.21 for farmers and US$1.15 for traders. The median willingness to pay for the hygrometer was $1 for both farmers and traders. In an analysis of the supply side of the market, the optimal retail price of the hygrometer was estimated to be about US$1.90.
   ii. Partnerships made: A local private company in Kenya (Bell Industries), which markets other Purdue technologies in Kenya, and is interested in marketing the hygrometer. Purdue is partnering with Global Good (a collaborative effort between Bill Gates and Intellectual Ventures to address some of humanity's toughest problems through the power of invention) to develop and later to evaluate protocols that use inexpensive humidity/temperature devices to measure moisture content of grains. Two train the trainer workshops were conducted in Malawi in May 2017 by Purdue FPL and PICS in collaboration with USAID FtF Agriculture Diversification (AgDiv) Program. The training included hands-on activities with the hygrometer and hermetic storage (PICS Bags).
   iii. Technologies ready to scale: Hygrometer and a protocol for its use to measure grain moisture content. (Protocol: a handful of grain is placed in a small, sealable plastic bag with the hygrometer. Moisture equilibrium is established within 15-30 minutes. If the relative humidity reading is above 65%, the grain is too wet for safe storage. Below 65% RH, the grain is ready for storage).
   iv. Technologies transferred: N/A
   v. Technologies scaled N/A

b) Transfer of extrusion technology to Kenya and Senegal.

   i. Steps taken – Two low-cost small scale extruders have been placed in Senegal (one at ITA and the other at local food processor's facility) and one in Kenya at the University of Eldoret. Consumer studies on acceptance and willingness to pay for instant flour products (fortified and

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

non-fortified) have been conducted in both countries and results show a strong interest and willingness to pay for the products. ITA has developed weaning food formulations that are ready for dissemination.

ii. Partnerships made: A local food processor, Mme. Astou Gaye Mbacke received the FPL extruder to use for her own processing and to train other local processors. The ITA actively worked to strengthen partnerships with Mme. Mbacke's Darou Salam Cereal Processing Unit., a key local partner in Touba. Support from the FPL project and the Government of Senegal was provided to upgrade the facilities to meet general hygiene specifications. This is in preparation for production of fortified instant flours for local feeding programs, of which there have been orders in excess of 500 MT. The renovation and upgrade of the processing facility was near completed in September 2017. A separate building has been assigned for instant flour processing using the FPL extruder and it has been outfitted. B. Hamaker traveled to Senegal in April 2017, in part to attend meetings organized by D. Traore, Senegal PI, and Mme, Mbacke, Touba FPL processing partner, with Senegal government officials and the director of the Senegal World Food Programme. Seven offices were visited. A Concept Note for support from the Senegalese government and WFP was requested, and submitted in May 2017. The concept note requests for additional extruders (one large-capacity extruder for Mme. Mbacke and 2 of the currently used low-cost model to place in other rural entrepreneur processor sites) and support of technical personnel to upgrade and expand the project. Further discussions have been held, and the team hopes for a decision on government support for the proposed activities by end of 2017.

iii. Technologies ready to scale: Extrusion technology with capability of producing a wide range of instant-flour based products

iv. Technologies transferred N/A

v. Technologies scaled N/A

VI) ENVIRONMENTAL MANAGEMENT AND MITIGATION PLAN (EMMP)

FPL is committed to put the mechanisms in place for environmental mitigation as outlined in the Environmental Mitigation and Monitoring Plan (EMMP). In Senegal two complete individual protection equipment sets were acquired for working with the insect impregnated A to Z Textile hermetic bags. 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 is stored on the Purdue University Research Repository (PURR) website managed by Purdue Libraries. PURR provides project space to manage data, and publishes datasets with Digital Object Identifiers (DOIs) and citations for Purdue PIs.

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. The project also holds an annual half-day WebEx meeting; this year's meeting occurred on July 12, 2017. Management team is exploring the possibility of conducting a face-to-face annual meeting in the coming fiscal year.

IX) OTHER TOPICS[13]

Dr. Cheryl O'Brien, Assistant Professor, San Diego State University, a gender consultant FPL continued to provide input and guidance for project teams on gender issues. Teams continued collecting gender-disaggregated data and sought Dr. O'Brien's input, as needed. A manuscript is being prepared for publication in peer-reviewed journal for the gender-focused study was conducted in the summer of 2016. Also, Dr. O'Brien attended Gender in Agriculture Partnership webinar "Closing the gender data gap for agricultural policy and investment" in the fall of 2016 and communicated with information with FPL team members. The gender focused discussions (FGDs) enabled capacity-building for 5 young women (4 students) in gender-related work including experience with organization, facilitation, translation and transcription. Based on the study results as well as additional research beyond FPL, Obrien 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 in year 4. O'Brien is also collaborating with Kansas State University's FTF PHL to strengthen gender integration across its teams in Ethiopia, Guatemala, Ghana, and Bangladesh and provides a linkage between the two innovation labs (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[14]

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

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

XI) FUTURE DIRECTION

The FPL looks to be effective and relevant in the two focus countries of Kenya and Senegal through development of practical and cost-effective solutions for grain drying, storage, and food processing in the humid topics. The solutions will be beneficial to end-users including smallholder farmers, food processors, and consumers in the focus countries and other Feed the Future countries. They will also be profitable for the manufacturers of the technologies, helping to create non-farm jobs. The FPL is also working to improve nutrition through food fortification strategies that are both market-driven and for use at the household level in food preparations. The strategies take advantage of the high-nutrient plant sources that are readily available but underutilized in the focus countries. Overall, the first two years of the project focused on technology development, on-station testing, and modification. In this fiscal year (Year 3), emphasis is on field-testing and technology adaptation/refinement to environments of operation, and selection of viable technologies for adoption. In years 4 and 5, the program will focus on aspects of technology adoption, scale-up, and assessment of potential for commercialization of viable technologies. 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. FPL will help to develop these value chains for markets. The FPL is also working to identify trends and opportunities for post-harvest grain research and engagement over the next 5 to 10 years, to expand the program and keep it relevant to the stakeholder needs.

Appendix 1: Drying and storage extension activities in Kenya

- KALRO participated in two regional agricultural extension and trade fairs namely Kakamega agricultural society of Kenya (14th-18th June 2017) and Kisumu (25th-29thJuly, 2017). The exhibitions are part of the annual calendar events of the Agricultural Society of Kenya targeting farmers and wider agricultural stakeholders.
  Through the FPL project, KALRO showcased the drying and storage technologies (Figure A) alongside other KALRO technologies.

Figure A1. Pictures from the Kakamega Agricultural Society of Kenya Trade Fair

- Over 1500 show participants consisting of farmers, traders, students, policy makers and other stakeholders visited the KALRO stand. They were sensitized on and exposed to grain post-harvest management, solar drying technologies, PICS, and use of hygrometers to measure moisture content.
- Hygrometers were offered for sale at the trade fair.