Small Extruder Creates Big Opportunities in Cereal Products for African Entrepreneurs

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Training of women and youth entrepreneurs on the small extruder developed by Purdue University.
(Photo courtesy of Moustapha Moussa)

A small single-screw extruder originally developed by Purdue University for a NASA mission to Mars has been repurposed to give African entrepreneurs a new income opportunity in instant cereal production. This small extruder allows entrepreneurs to use low cost local crops such as millet and sorghum to quickly and efficiently produce high demand instant cereal products ranging from couscous to instant porridge. The extruder processed cereal products have shown benefits such as increased nutritional value, reduced rancidity, and improved taste, color, texture, and consistency. A supporting hub-and-spoke food innovation system allows users to share ideas and new product and process specifications.

Food Science in Action:

- ✓ Food Engineering
- ✓ Food Processing
- ✓ Food Quality
- ✓ Product Development
- ✓ Sensory Science
- ✓ Nutrition

Introduction

Africa's economy has expanded significantly in recent years due to factors such as industrial development, increased foreign investment, infrastructure improvements, and a growing middle class (although not uniformly across all countries). This has been driving an increased demand for convenience foods such as couscous and instant cereals, which are popular in many countries. This demand is often met with imported, wheat-based products despite the wide availability of nutritious, locally-grown grains like millet and sorghum, which are the major staple crops in the semi-arid Sahelian region of West Africa.

In many African countries, couscous and instant cereals are available only in limited quantities in the retail market since they are produced at a small scale through traditional production

methods that are laborious and time-consuming. One example in Niger is traditional West African pearl millet couscous, which is made from locally-grown pearl millet. From milling into flour, mixing with water, and agglomerating by hand-rolling to the final steps of steaming, drying, and sieving, the process of manufacturing traditional pearl millet couscous can take as long as three days.[1]

To address this problem, researchers at Purdue University set about modifying a small, single-screw extruder originally developed by Purdue for a NASA Mars mission so that it could be easily used by entrepreneurs in Africa. The hope was that this low-cost extruder could improve the rate of food processing, reduce drudgery, and stimulate small- to medium-scale food production enterprises.

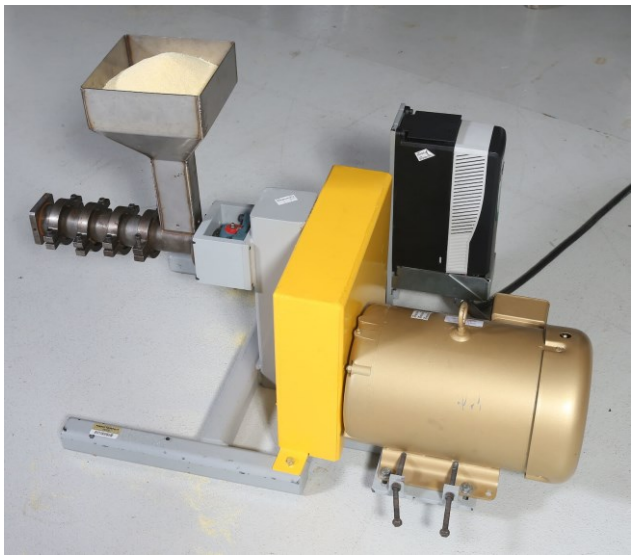

Figure 1. *Purdue University's small extruder. (Photo courtesy of Purdue University [Purdue Agricultural Communication/Tom Campbell])*

Project Overview

In the early 2000s, with funding from NASA, Purdue professors of biological and agricultural engineering Martin Okos and Osvaldo Campanella developed a reduced-size, single-screw extruder for processing food to be grown on Mars.[2] The extruder could be used to cook grains and soybeans, as well as extract oil.[2] Although the extruder has yet to be deployed for its original mission, the small scale of the extruder hinted at another opportunity: use by food processing entrepreneurs in developing countries.

Compared to commercial extruders (which could cost about $200,000 at that time), the Purdue small extruder (Figure 1) could be sold for one tenth of the cost.[2] In addition, it could be run without external heating coils or steam (just electricity) and would not require expensive imported replacement parts.[2] The extruder's simplicity and output—about ¼ ton per day—also made it a good fit for food startups.[3]

Since then, food science professor Bruce Hamaker and former graduate student Moustapha Moussa have been working through the USAID Feed the Future Innovation Lab for Food Processing and Post-Harvest Handling at Purdue to introduce the potentials of the small extruders in Africa. Moussa is based in West Africa, which allows him to make these connections and test the extruder in real-world settings.

Currently, Purdue extruders can be found in Senegal (three with food processing entrepreneurs and one at a university), Niger (one at a research institute), and Kenya (one at a university), as well as Tanzania, Burkina Faso, and Mali.[3] The users range from entrepreneurs and women's groups to universities and government research institutes.[3]

Users in Africa have been most interested in using the small extruder to produce instant cereal-based products, such as couscous and instant porridges, particularly from locally-produced millet, sorghum, and maize. Where consumers have shown a willingness to pay extra for nutrient fortification (i.e., market-led nutrition), some processors are adding a vitamin-mineral premix or locally-grown natural fortificants like baobab, moringa, and hibiscus (which all enhance iron bioavailability, among other benefits).[3] A newer strategy for making fortified extruded products to improve rural nutrition uses a hybrid approach, wherein natural fortificants are added to signal to consumers a more nutritious and healthier product, while a premix is included to ensure nutrient targets are reached.[3] About 50% of the products made in Tanzania with the extruder are fortified.[3]

Data and documentation on new product testing is also shared with extruder users through a hub-

and-spoke food innovation system in West Africa, with information distributed from a central food innovation center (the hub) to rural food processing centers, such as those run by rural women's associations (the spokes).

Through a licensing agreement, Technochem International in Boone, Iowa produces Purdue's small extruder, which measures approximately 48" (L) x 39" (W) x 6" (H).[4] The single-screw extruder has a 7.5 HP electric motor, two variable frequency drives (one for 230V and one for 380V), and other standard extruder components, including an extruder shaft assembly, a feed chamber, multiple barrels, single- and double-flight screws, an in-line thermometer, a feed chute, and an oil expelling attachment,[5] which can be replaced with a die to shape material if oil extraction is not required. It also has the potential to be adapted to thermal energy sources for rural locations by using a small thermal motor fueled with gas or oil to generate electricity for its operation.[4] Purchase of the extruder includes an illustrated manual that provides step-by-step assembly instructions.

The extrusion process involves feeding food materials and water into the extruder's barrel, where they are mixed, heated, and pressurized by the rotating screw. As the screw pushes the material forward, friction generates heat, cooking the food, with the amount of heat controlled by adjusting the speed and size of the screw components. Too little heat can result in inadequate cooking, whereas too much heat risks burning the product. The cooked material is then forced through a die or other attachment. To create an instant cereal product, a cutter may be installed to chop the extruded material (known as the extrudate) into small pieces, followed by cooling and drying to reduce moisture content. Milling is used to reduce the particle size and achieve the final texture and consistency.

Food science is critical to this project in many ways. Food processing and engineering principles are central due to the roles of extrusion cooking and equipment modifications in developing an entrepreneur-sized extruder that can produce instant cereal products. The efforts to combine different grains and incorporate vitamin-mineral premixes and locally-grown nutritious crops like baobab make use of product development, nutrition, and sensory science. Improvements achieved in product taste, color, texture, and consistency compared to manual production methods show how food quality also has a prominent role in this project.

> *"Food science is becoming more important in development."*
>
> ***Professor Bruce Hamaker, Purdue University[3]***

Researchers involved in the project have identified a number of potential benefits the small extruder could have in Africa. First, it provides substantial income and empowering opportunities for small entrepreneurs (including women and youth, who are being targeted as part of this project (Figure 2)), with the ¼-ton per day product output ideally suited for an entrepreneur.[3] The extruder is also versatile, able to produce a variety of in-demand products, including couscous and fortified flours for instant porridge, faster and more efficiently than with traditional manual methods. In fact, the traditional production methods for some of these products are not able to keep up with market demand, so consumers often turn to imported instant wheat products instead.[3] Using the extruder could help meet consumer demand and support local millet, sorghum, and maize farmers, thereby strengthening the supply chain.

Successes

Use of the small-scale extruder in developing countries has shown several positive impacts in key staple crops and diverse food products at multiple locations. Initial work in Niger and Senegal primarily focused on developing instant sorghum and millet porridges, later expanding to diversify products and enhance nutritional value through the incorporation of additional ingredients and process optimization. More recently, the small extruder has been tested in the development of couscous and related products from locally available crops using the extrusion process for the first time.[1] Moreover, the development and optimization of these products using the small extruder has resulted in broader impacts such as creation of sustainable market-

Figure 2. *Millet extrudate coming from extruder during urban youth and women processors training. (Photo courtesy of Moustapha Moussa)*

driven food processing models that can benefit smallholder farmers and improve nutrition of local communities not only in Niger and Senegal, but also Nigeria, Burkina Faso, Mali, and Tanzania.

Higher Quality

An early study looked at obtaining higher quality sorghum porridge, a product commonly consumed in West Africa. The study showed that instant/pre-gelatinized (pre-cooked) flours produced by the small extruder resulted in more stable thin and thick porridges (locally known as fura and tuwo, respectively) with smoother textures, a brighter white-yellow color, improved aroma, and better taste when compared with conventionally prepared fura and tuwo.[6] These porridges scored better with consumers in four different locations in Niger when compared to the traditional porridge.[6] The study also found that the small extruder flour processing had achieved a higher material fragmentation, which resulted in a lower viscosity, more stable porridge.[6] Moreover, it suggested that such lower viscosity could be beneficial in children's feeding programs by allowing higher energy densities to be achieved.

In the last few years, additional quality improvements have been found around the use of the small extruder—including improved flavor and flavor stability of pearl millet porridges[7,8] and the reduction of aflatoxin contamination.[9]

Improved Nutritional Value

Following the initial experiences with instant sorghum and millet porridges, more focus was put into product diversification with improved nutritional value. Although this was done mostly by incorporating additional ingredients into the formulations, process optimization also showed the ability to increase nutritional value, such as by improving provitamin A content and iron bioavailability through reduction of phytate content.[10] In one study, instantized fruit/vegetable-cereal blends using powdered mango, papaya, and carrot added to whole grain and decorticated millet showed reasonable recovery of provitamin A carotenoids for all blends, as well as creating texture variety (with the mango and papaya producing thinner porridges and the carrot producing thicker porridges).[11,12]

In another study, affective tests and experimental auctions with 200 consumers in Senegal showed that consumers did not identify any differences in appearance, aroma, or taste between an extruder-produced instant millet porridge and a conventional millet porridge and that they were willing to pay a modest premium when information about the benefits of the instant porridge was provided.[13] For mango- and carrot-fortified instant porridges, they were willing to pay a large premium when presented with information on the benefits.[13]

Further efforts were made to improve the nutritional value of the developed blends by introducing other native crops such as baobab fruit (*Adansonia digitata*), moringa (*Moringa oleifera*), maize, amaranth, and orange-fleshed sweet potatoes (OFSP). This resulted in increased content and recovery of provitamin A (of 60% to 90.3%) and iron, while also showing positive acceptability scores by consumers.[14,15] An infant formula was developed with a similar approach that included the use of peanuts and cowpea for protein, along with mango, papaya, carrot, or baobab fruit for flavor enhancement, with all formulations showing high rates of acceptability among 21 panelists in Senegal.[16] Higher nutritional and health values of extruded flours for instant porridge through the formation and fermentation of fiber has also been noted, along with improved marketability.[17,18]

Increased Efficiency

The use of the small extruder was also tested to produce a pearl millet couscous that can be made efficiently enough to compete with the imported durum wheat couscous in the market. Although traditional pearl millet couscous is popular in West Africa, its preparation is laborious and time-consuming, leading to a supply that often cannot keep up with consumer demand. The traditional process, which can take up to three days to complete, involves milling, mixing with water, manual agglomeration, steaming, drying, and sieving.[1] The small extruder provides a high pressure, high temperature process alternative that speeds up some of the slowest steps, although final drying and sieving are still required.[1]

> *"To our knowledge, this is the first report describing a process to produce couscous-type agglomerated products using high pressure, high temperature extrusion cooking and direct drying and milling of the cooked extrudate."*
>
> ***Professor Bruce Hamaker, Purdue University[3]***

The extrusion approach showed an increase in throughput from 50 kg per day to about 350 kg per day with the same amount of labor.[1] Key product benefits of the extruded pearl millet couscous were a more consistent color and texture, as well as reduced rancidity (due to the much faster processing time).[1] Moreover, depending on the millet variety used, this novel couscous showed comparable sensory responses to conventional versions when evaluated by consumers in Niamey, Niger.[1]

Facilitation of Connections

After these promising results with the small extruder, expanding the market potential and broader impacts of this technology became the next step. For this purpose, a hub-and-spoke food innovation system was implemented, resulting in three major impacts: 1) increased income opportunities for women and youth processors; 2) increased development of consumer/market-tested products that improve nutrition; and 3) expanded markets for the extruder-made products. By 2023, the hub-and-spoke system consisted of 3 hubs (Maradi, Zindigori, and Kaboe Koura) and 15 spokes in Niger, 3 hubs in Burkina Faso (Lebda, Amdentinga, and Gonsé), 1 hub in Mali (Wakoro), 1 hub in Tanzania (plus 3 rural spokes making sales of maize products with profit), and 1 hub in Nairobi.[19]

Income Generation

As an example of success in these major impacts, the collaborative efforts in hubs and spokes in Niger translated to a total product sales of USD 283M in 2022, with 1 of the spokes sites producing consistent sales of over USD 10M/year and an additional 4 with sales of USD 2-4M/year between 2020 and 2022.20 Moreover, a total of

19 products currently exist in Niger, with 4 of them fortified with iron, zinc, and vitamin A. Sales and profit data showed that the fortified flours for instant porridge are the best-selling (and most profitable) products, as they are purchased by women from more than 67 nearby neighboring villages (located from 15 to 150 km from spokes centers) and save children from malnutrition in more than 60 rural markets and 30 community health centers.[20] One entrepreneur in Senegal, Madame Membaque, who owns two extruders, has already grossed USD 350,000 for her fortified flours.[3] She contracts in advance with local millet growers to ensure a high quality and constant supply, paying them slightly above the market rate.[3] In this case, the extruders incentivize farmers to produce higher quality crops, increase the income of growers, and help develop, innovate, and expand the millet supply chain.

> *"In Senegal, one successful entrepreneur is even paying farmers a premium price for their crops to ensure she gets high quality raw material for her extruder operation."*
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> ***Professor Bruce Hamaker, Purdue University[3]***

Looking Ahead

Increased entrepreneurship and commercial value from the small extruder technology is likely around the corner as part of the efforts by the Feed the Future program, led by the Collaborative Research on Sorghum and Millet Innovation Lab at Kansas State University. Current and upcoming work is focused on three areas:[21]

1. Developing new formulations and consumer/market-tested products acceptable to children (and adults)
2. Supporting urban (entrepreneurs) and rural (women's associations) processors with technologies, formulations, processes, and nutritional improvements to products
3. Expanding markets and improving nutrition through processors growing their reach

Moreover, forthcoming is a publication describing efforts to measure the nutritional impact of the introduction of fortified flours and the geographical range of the impact driven by central rural food innovation centers.[19] The results of this research, done in 2023 for Niger Rural Joint Project and based on nutritional assessment surveys of 3000 participants, indicate that diet diversity, as measured by World Food Programme Food Consumption Scores, was significantly higher than matched control communities (with household food expenditure also somewhat higher).[19] The rural food processing centers were found to have multiple positive effects in the communities beyond just the production of nutritionally-fortified products for local markets.[19] Also available soon will be evidence on increased willingness to pay (WTP) for products with improved nutritional value in Kenya.[17]

Hamaker said that cost is still a barrier and that reducing the cost of manufacture will continue to be part of their efforts.[3] In fact, lower capacity, more affordable single-screw extruder design and testing is being done domestically in Nigeria.[22] While it is not expected that the equipment would be used at the household level, lower cost would allow more entrepreneurs to join the hub-and-spoke innovation system, with a special emphasis being placed on youth entrepreneurs.

At a technical level, food science disciplines will continue to be core to this work as researchers determine if the current processes work with new crop varieties that have higher nutritional potential. Furthermore, while the small extruder has been found to produce some degrading effects on certain nutrients, solutions are already being found through the use of additional ingredients and optimization of process parameters.

References

1 Moussa M, Ponrajan A, Campanella OH, Okos MR, Martinez MM, Hamaker BR. Novel pearl millet couscous process for West African markets using a low-cost single-screw extruder. *Int J Food Sci Technol*. 2022;57:4594–4601. Available from: https://doi.org/10.1111/ijfs.15797

2 Purdue University. Mars technology creates solutions in Africa; 2017 Apr 20. Available from: https://ag.purdue.edu/news/2017/04/mars-technology-creates-solutions-in-africa.html

3 Hamaker B. Purdue University small extruder [Oral communication]. 2020 Nov 2.

4 Moussa, M., Purdue University small extruder [Oral communication]. 2023 Jul 21.

5 Technochem International, Inc. Technochem Mini-Extruder Manual; [cited 2023 Jul 24].

6 Moussa M, Qin X., Chen, LF, Campanella OH, Hamaker, BR. High-quality instant sorghum porridge flours for the West African market using continuous processor cooking. *Int J Food Sci Technol*. 2011;46:2344–2350. Available from: https://doi.org/10.1111/j.1365-2621.2011.02755.x

7 Onyeoziri I, Torres-Aguilar PC, Hamaker BR., Taylor JRN, de Kock H. Can extrusion cooking improve and/or stabilize the flavour of pearl millet porridges? [Presentation]. 2019 Sep 3. Available from: https://saafost.org.za/Events/BRANCH_All/2019/SAAFoST2019/Presentations/Wednesday/11h00%20-%20Plenary%20-%20Onyeoziri%20-%20Wednesday.pdf

8 Onyeoziri I, Torres-Aguilar PC, Hamaker BR, Taylor JRN, de Kock H. Descriptive sensory analysis of instant porridge from stored wholegrain and decorticated pearl millet flour cooked, stabilized and improved by using a low-cost extruder. *J Food Sci*. 2021;86(9):3824-3838. Available from: https://doi.org/10.1111/1750-3841.15862

9 Hegwood ML. Evaluation of Small-Scale Extrusion for Aflatoxin Decontamination of Maize in Kenya. Purdue University Graduate School. Thesis. 2020. Available from: https://doi.org/10.25394/PGS.12698465.v1

10 Sow S, Sarr F, Mertz C, Cisse M, Fall S, Diallo D, Morel G. Effects of Fermentation, Germination, Roasting and Mono-Screw Extrusion Cooking on the Phytate and Iron Contents of Millet Souna Produced in Senegal (*Pennisetum Glaucum*). *J Nutr Health Food Sci*. 2018;7(3):1-7. Available from: https://symbiosisonlinepublishing.com/nutritionalhealth-foodscience/nutritionalhealth-foodscience159.php

11 Ndiaye C, Sarr F, Traore D, Debelo HA, Sow S, Hamaker BR, Ferruzi MG. Impact of Extrusion on Fruit/Vegetable-Millet Blends on Recovery of Carotenoids and Product Physical Properties. Conference: IFT 2016 Product Development Division. 2016. Available from: https://www.researchgate.net/publication/307956218_Impact_of_Extrusion_on_FruitVegetable-Millet_Blends_on_Recovery_of_Carotenoids_and_Product_Physical_Properties

12 Ndiaye C. Quality and Nutritional Impacts of Extrution on Pearl Millet and Nutrient Dense Native Plant Blends. Purdue e-Pubs Open Access Dissertations. 2018. Available from: https://docs.lib.purdue.edu/open_access_dissertations/1877

13 De Groote H, Kariuki S, Traore D, Taylor JRN, Ferruzi MG, Hamaker BR. Measuring consumers' interest in instant fortified millet products - a field experiment in Touba, Senegal. Conference of the African Agricultural Economics Association. 2016. Available from: https://ageconsearch.umn.edu/record/246973/

14 Ndiaye C, Martinez MM, Hamaker BR, Campanella OH, Ferruzi MG. Effect of edible plant materials on provitamin A stability and bioaccessibility from extruded whole pearl millet (*P. typhoides*) composite blends. *LWT*. 2020;123. Available from: https://doi.org/10.1016/j.lwt.2020.109109

15 Emmaculate S, Wandayi OM, Ooko AB, Kadenyeka MV. Consumers' acceptability of extruded maize-sorghum composite flours fortified with grain amaranth, baobab and orange fleshed sweet potatoes. *Afr J Food Sci*. 2020;14(9);274-284. Available from: https://foodtech.uonbi.ac.ke/node/336

16 Diop M, Sow S, Dieme E, Ndiaye C, Gaye ML, Traore D, Development of Extruded Senegalese Infant Formula from Mixtures of Pearl Millet and Grain Legumes. *J Nutr Health Food Sci*. 2018. Available from: https://symbiosisonlinepublishing.com/nutritionalhealth-foodscience/nutritionalhealth-foodscience149.pdf

17 Ayua EO. Studies on Extrusion Processing of Instant Porridge Flours for African Processor Optimization, Acceptance, Marketability for Consumers, and Improvement in *In Vitro* Fecal Fiber Fermentation. Purdue University Graduate School. Thesis. 2021. Available from: https://www.proquest.com/openview/ab515e6ac8f293ae62bd5cf8f0b69564/1?pq-origsite=gscholar&cbl=18750&diss=y

18 Torres-Aguilar PC, Hayes AMR, Yepez X, Martinez MM, Hamaker BR. Formation of slowly digestible, amylose–lipid complexes in extruded wholegrain pearl millet flour. *Int J Food Sci Technol*. 2023;58:1336-1345. Available from: https://doi.org/10.1111/ijfs.16294

19 Moussa M, Purdue University small extruder [Written communication]. 2024 Jun 29.

20 Feed the Future Collaborative Research and Sorghum and Millet. Expanding Markets for

Sorghum and Millet Farmers in West Africa Through Strengthening of Women and Youth Processors and Nutrition-based Promotion of Products [cited 2024 Jan 28]. Available from: https://smil.k-state.edu/expanding-markets/

21 Feed the Future Expanding Markets for Sorghum and Millet Farmers in West Africa Through Strengthening of Women and Youth Processors and Nutrition-based Promotion of Product. Phase II Year 9 Report [Presentation]. 2023 Feb. Available from: https://smil.k-state.edu/wp-content/uploads/2023/03/2023-ExpandingMarketsSorghumMilletFarmersWestAfricaStrengtheningWomenYouthProcessorsNutritionBasedPromotionProducts.pdf

22 Abioye AO, Olajide JO, Ngoddy PO. Single-Screw Laboratory Extruder for Production of Expanded Products: Design, Construction and Performance Testing. *J Agr Sci Tech*. 2019;293-304. Available from: https://www.davidpublisher.com/index.php/Home/Article/index?id=41520.html