Chapter 5
Orange-Fleshed Sweetpotato Puree: A Breakthrough Product for the Bakery Sector in Africa

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Abstract Replacing some of the wheat flour in breads and pastries with OFSP (orange-fleshed sweetpotato) puree can increase the market demand for these nutritious varieties and would offer economic opportunities for smallholders, including women and youths. The technology to make sweetpotato puree has been well developed in industrialized countries since the 1960s. Techniques fine-tuned by RTB allow OFSP puree to be stored in plastic bags for 6 months, without refrigeration. Private companies in Malawi and Kenya are now manufacturing the puree and selling it to bakeries that substitute OFSP puree for up to 40% of the white wheat flour in bread and other baked goods. Consumers like the bread that is sold in supermarkets and bakeries. Food safety protocols ensure that the puree is part of safe,

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healthy products. The OFSP seed is available to smallholder farmers, who are linked with processors who buy the roots. Business models suggest that processing puree is profitable. The Scaling Readiness approach is helping to ensure that more farmers, processors, and consumers benefit from OFSP.

5.1 Introduction

Sweetpotato is a climate-smart root crop that adapts well to low rainfall, different altitudes, and poor soils. It requires minimal labor or other farm inputs. It is a hardy crop with low risk of crop failure (Abidin et al. 2017; Low et al. 2020). These farmer-preferred agronomic traits, combined with relatively high nutritional value, make the sweetpotato an ideal crop for enhancing food security and improving livelihoods in African communities. The biofortified orange-fleshed sweetpotato (OFSP) varieties have high levels of β-carotene, a precursor of vitamin A in the human body. OFSP is a proven, effective, and sustainable source of vitamin A, significantly contributing to the fight against vitamin A deficiency (VAD) in Africa (Low et al. 2007; Girard et al. 2017). OFSP also has vital, life-promoting phytochemicals that enhance protection from peroxides (Abong et al. 2020).

Despite the importance and knowledge of the nutritional benefits of OFSP, it remains generally underutilized, possibly because the roots are highly perishable, which depresses their market value. Low prices can subject OFSP to market losses, discouraging farmers from planting the varieties. Consumers prefer white-fleshed sweetpotato varieties, further reducing demand for OFSP (Moyo et al. 2021). The sweetpotato's seasonality further limits the periods when consumers have access to OFSP. Urban consumers eat less OFSP because they prefer convenient, ready-to-eat foods over roots that need to be cooked. Fresh sweetpotato is eaten boiled, steamed, roasted, or fried in most African communities (Mwanga et al. 2021), so processing OFSP roots into a puree creates more options for consuming them, improving their availability in cities and reducing food waste and losses.

OFSP puree can replace some of the white, wheat flour in baked and fried products. Making puree overcomes the challenge of perishability and seasonality of the roots by processing them into a more shelf-stable product that can be incorporated

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into diets even when the fresh roots are off-season (Wanjuu et al. 2018). Bread is a staple food in much of Africa, particularly in cities. Incorporating OFSP puree into bread would significantly increase the number of OFSP consumers and reduce VAD (Awuni et al. 2018; Owade et al. 2018). OFSP puree can replace up to 50% of the wheat flour in bread, while reducing sugar (90%) and fat (50%) and eliminating artificial colorings (egg yellow). The baked bread retains over 50% of the β-carotene, and the OFSP puree improves the texture of wheat products, making them easy to chew and digest (Wanjuu et al. 2018).

OFSP puree in bakery products is new and unique to sub-Saharan Africa (SSA) and shows great potential for expansion. African millers spend millions importing wheat, with East African countries being among the top importers. Kenya's wheat import bills are estimated at $250 million, Tanzania's at $150 million, Uganda's at $53 million, and Rwanda's at $35 million per year. Substituting some of this wheat flour with locally produced OFSP puree in popular baked goods would save African economies much needed foreign currency.

Over the last decade, the International Potato Center (CIP) has gained considerable experience in product development and marketing of bakery products in which 20–45% of the wheat flour is replaced with OFSP puree: successfully commercialized in Kenya, Malawi, Rwanda, and Burkina Faso and piloted in Ethiopia, Uganda, Ghana, Nigeria, Tanzania, The Gambia, South Africa, and Mozambique. The OFSP puree value chain activities have created market opportunities for smallholder sweetpotato farmers, especially women and youths, by increasing the value of the crop. Higher farm-gate prices for roots could encourage greater use of farm inputs, which would help to close the existing yield gap, increasing the availability of sweetpotato in rural areas and the accessibility of nutritious OFSP to urban consumers.

5.2 The Evolution of Sweetpotato Puree Processing

The technology for processing OFSP roots into puree was developed in the United States in the 1960s (Kays 1985), e.g., for baby foods, baked products, and other foods. Processing includes root washing, peeling, cutting, steaming/blanching or precooking, finish cooking (with temperature-time programs suitable for starch conversion by endogenous amylolytic enzymes to obtain the products with targeted maltose levels and viscosities), and grinding into puree. In many countries, processing of sweetpotato paste or puree is traditionally practiced at the household and small-scale levels by boiling or steaming fresh roots and then mashing or grinding them. The puree is an ingredient in many foods, including baby foods, soups, pies, cakes, ice creams, breads, and other products (Collins and Walter Jr 1992; Woolfe 1992; Truong 1989, 1994; Truong and Avula 2010).

The development of OFSP beverages, jam, and ketchup with sensory and nutrient attributes comparable to fruit-based products in the early 1990s raised interest among research institutions in several sweetpotato-producing countries including

India, Japan, Malaysia, the Philippines, and the United States (KNAES 1996; Padmaja 2009; Payton et al. 1992; Sankari et al. 2002; Tan et al. 2004; Truong 1992). Transfer of the processing technologies to farmer organizations, small-scale processors, and food companies for pilot testing and market development was conducted in the Philippines (Truong 1992).

In Japan, the puree from white-, orange-, and purple-fleshed sweetpotato varieties was commercially produced by cooperatives and small manufacturers to make ice creams, jams, juices, confectionary, and breads (Duell 1992; Katayama et al. 2017). However, sweetpotato puree was less common than sweetpotato flour as a substitute for wheat flour in bakeries around the world. In two coastal towns of Peru (Cañete and Chincha), OFSP in the form of grated raw or paste of steamed roots (depending on the availability of processing equipment) was substituted for up to 30% of the wheat flour to improve the β-carotene content of a commercial bread, *pan de camote* (Woolfe 1992). Recently, orange-fleshed sweetpotato puree has replaced 20–50% of wheat flour in cookies, donuts, and breads by some commercial bakeries in Ghana, Kenya, Malawi, Rwanda, and Uganda (Bocher et al. 2017).

Challenges for the puree processing industry include the following: (1) adjusting the process to account for differences in carbohydrate content and amylase activities among variety types, postharvest curing, and storage conditions to produce consistent and high puree quality, and (2) preservation technology that produces a shelf-stable product for convenient use in processed foods. Several techniques were later developed to produce purees with consistent quality, despite the varietal differences in carbohydrate content, starch-degrading enzyme activities, and postharvest handling (Collins and Walter Jr 1992).

5.3 Development and Commercialization of Aseptic Shelf-Stable OFSP Puree by Continuous Flow Microwave Processing

Purees can be preserved by canning, freezing, or refrigerated storage with acidification (with citric acid) or by adding preservatives such as potassium sorbate or sodium benzoate (Bocher et al. 2017; Pérez-Díaz et al. 2008; Musyoka et al. 2018a). However, poor product quality due to excessive heat in conventional cooking, the high cost of investment associated with frozen products, and the use of preservatives are the main hurdles for widespread applications of sweetpotato purees in the food industry. An improved canning process was developed for OFSP puree involving flash sterilization and aseptic filling/packaging to produce a shelf-stable product (Smith et al. 1982). However, validating and scaling up the technology did not proceed to commercial development in the United States.

Continuous flow microwave heating and sterilization technologies were initiated at North Carolina State University (NCSU) in the mid-1990s with support from the

Center for Aseptic Processing and Packaging Studies (CAPPS). The initial push for these developments was to enable industrial processing and commercialization of complex multiphase foods in sterile packaging formats, such as low acid soups and stews, and to retain native, typically heat-sensitive flavors, colors, textures, and nutrients like vitamins and antioxidants. Since then, many studies have been performed on other difficult-to-heat and poorly conductive foods and beverages such as salsas, dairy and plant-based milks, smoothies, baby foods, cheese sauces, other sauces, and cooking blends and pureed, homogenized, and diced vegetables and fruits like strawberries, peaches, mangos, blueberries, bananas, and pineapples. To date, over 70 FDA letters of no objections/no questions (LNO) have been issued for a variety of products processed and commercialized using several configurations of continuous flow microwave processing.

In the early 2000s, a novel process for rapid sterilization and aseptic packaging of OFSP puree using a continuous flow microwave system was successfully developed. The product packaged in flexible plastic containers had similar color, carotene retention, and apparent viscosity as the non-sterilized puree and was shelf-stable for at least 12 months (Coronel et al. 2005; Kumar et al. 2008). With this technology, consistently high-quality puree from sweetpotato roots (30–40% of the crop) could be packaged into virtually unlimited container sizes (up to 200 or 250 liters) as a functional ingredient for the food processing industry (Fig. 5.1). In 2008, the developed technology was transferred to a start-up company, Yamco. This large-scale factory has operated with an output of up to 20,000 kg of aseptic puree per day to supply a high quality, shelf-stable functional ingredient to companies manufacturing baby foods, beverages, soups, chips, baked products, and pet foods, among others. The Yamco factory is the first in the world to use a continuous flow microwave sterilization system for the commercial production of shelf-stable OFSP puree.

This rapid expansion of OFSP as an ingredient in food manufacturing has been influenced by the high retained nutritional values and convenient bulk packaging formats for further processing with easy portioning and conveyance/pumping. Previously available puree bulk packaging formats were in cans, 5-gallon plastic buckets of frozen product, or aseptic packaging using conventional (heat exchanger) methods of sterilization, all of which had significant shortcomings in quality levels, energy usage for storage, and ease of use or stability during preparation or defrosting.

After developing and testing the sterilization and shelf-life protocols, the microwave sterilized puree product was compared to similar products produced by other technologies (Table 5.1).

Advanced thermal (microwave) processing of sweetpotato in the U.S. is now used to make dozens of commercial products, including snacks, pie fillings, ice creams, pastas, bakery products, beverages, distilled alcoholic beverages like sweetpotato vodka and bourbon, soups, sauces, vegetable blends, and baby foods.

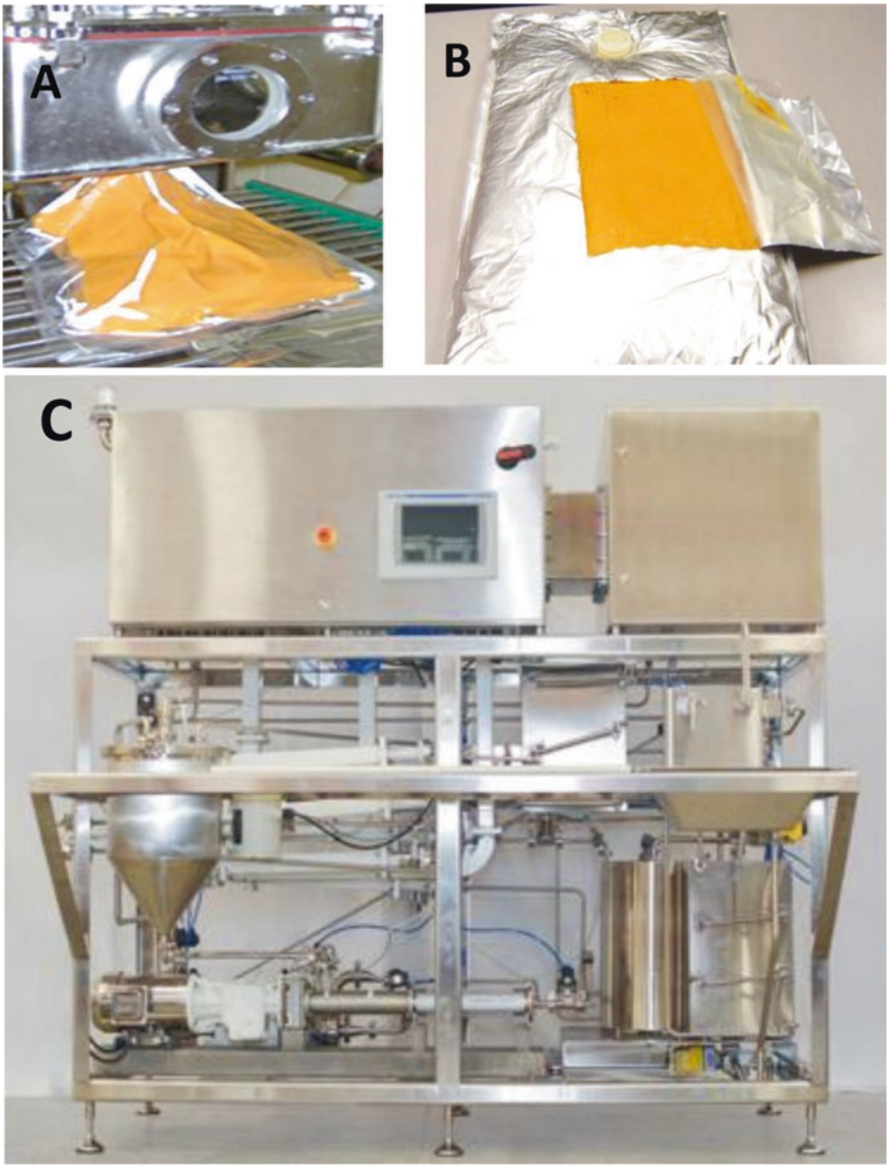

Fig. 5.1 Aseptically packaged OFSP puree produced by the first generation of continuous microwave heating system using a single-head Astepo aseptic filler (**a**) for a pilot scale or LiquiBox StarAsept aseptic filler for commercial production (**b**) in the early 2000s. Photo credits: VD Truong (NCSU). (**c**) Fourth industrial/commercial generation of continuous flow microwave heating/sterilization technology – 24 kW 2450 MHz processing installation at SinnovaTek/FirstWave Innovations in Raleigh, NC. Technology is commercialized by SinnovaTek Inc. under the Nomatic trademark. A factory using this technology has been set up in Kenya since 2019. (Photo courtesy of SinnovaTek Inc.)

Table 5.1 Sweetpotato puree comparisons: continuous flow microwave (first column) aseptic puree vs. other types

	Puree type				
Attributes	Microwave	Fresh	Frozen	Canned	With preservatives
Commercially sterile	Yes	No	No	Yes	Yes
Ambient storage	Yes	No	No	Yes	Yes
Superior natural color	Yes	Yes	No	No	No
Superior flavor	Yes	Yes	No	No	No
Fresh appearance	Yes	Yes	No	No	No
Preferred texture	Yes	No	No	No	No
Ease of use	Yes	No	No	No	Yes
High beta-carotene retention	Yes	Yes	No	No	No
% Preferred (NCSU consumer test)	68	25	1	5	1

Fig. 5.2 Fresh OFSP puree (**a**) is packed in food-grade plastic bags that are vacuum sealed. (Photo credit: N. Ronoh (CIP)). (**b**) The fresh puree can either be made using peeled roots. (Photo credit: S. Quinn (CIP)). (**c**) A high-fiber puree can be made with unpeeled roots. (Photo credit: CIP)

5.4 The Development of OFSP Puree Inclusive Value Chain in Africa

The rapid growth of African cities is fueling the demand for safe, affordable processed foods, opening up a huge market for OFSP puree as an ingredient in processed foods. Conventionally packaged puree (Fig. 5.2) requires cold chain storage, a major bottleneck to expanding the use of fresh puree in Africa.

Puree processors need to invest in storage facilities to use during the harvest season, to store supplies for the off-season, but this implies a high cost of electricity. Also, the informal food sector is growing in African cities, but few informal traders can afford refrigeration. Therefore, adopting technologies to produce high-quality, shelf-stable OFSP puree in Africa is crucial to allow millions of consumers to access affordable, vitamin A-rich foods throughout the year. This could increase food availability in many food-insecure African countries.

OFSP puree can be treated with preservatives before being packaged and stored for 3–6 months at room temperature. A combination of potassium sorbate, sodium benzoate, and citric acid with vacuum packaging eliminates the need for cold storage for up to 6 months with little loss of β-carotene (Musyoka et al. 2018a). The OFSP puree with preservatives was piloted in Kenya through a partnership with Organi Limited, a sweetpotato processing company based in Homa Bay.

OFSP puree can also be packaged using the aseptic filling technology. This process sterilizes both the product and the packaging material, eliminating the need to add preservatives while prolonging the shelf life of the puree. The OFSP puree can then be stored at room temperature for up to 12 months, enabling informal vendors without cold storage facilities to safely use the product to make cooked foods. A source of affordable packaging pouches was identified, which had been a major bottleneck for scaling this approach. This technology for OFSP puree processing has been piloted in Kenya, Uganda, Ethiopia, and Rwanda through partnerships with private sector entities. It is now being introduced under the BioInnovate project with CIP and partners in Kenya, Rwanda, Ethiopia, and Uganda (BioInnovate 2019). However, further research is needed for this technology to be fully implemented due to the high risk of spore survival and growth of proteolytic *Clostridium botulinum* during storage at room temperatures, with the accompanying high hazard of botulinum toxin formation. Ultimately, a preservative-free OFSP puree is more marketable with more consumers seeking chemical-free food.

As described in Sect. 5.3, OFSP can also be processed into aseptic purees using a continuous flow microwave system to obtain a shelf-stable product. With funding from the UK's DFID, now Foreign, Commonwealth & Development Office (FCDO), under the Development and Delivery of Biofortification at Scale (DDBio) project, CIP partnered with a Kenyan agro-processing company specializing in preserving fruits and other crops, Burton and Bamber (B&B) Limited, to establish the first continuous flow microwave system for sweetpotato purees in Kenya, which will be commissioned in the second half of 2021. CIP worked with researchers from NCSU and SinnovaTek LLC in Raleigh, NC, to provide B&B support with farmer training, certification for Global GAP, and crop management. B&B buys fruits and sweetpotatoes from farmers and sells the produce at supermarkets. B&B encouraged sweetpotato farmers to act as decentralized vine multipliers (DVMs) to supply disease-free sweetpotato planting material (seed) to nearby farmers. Farmers in east and central Kenya were trained in global GAP and to supply OFSP fresh roots for puree processing to B&B.

While investment is increasing in the food sector, small and medium agribusinesses in most developing countries are still capital constrained. New innovative products like biofortified foods require greater visibility and positioning for future commercial investing. CIP's investment in B&B to acquire OFSP puree processing equipment and aseptic packaging is expected to return at least the nominal principal. Positive social and environmental impact is part of the business strategy. CIP also worked with Euro Ingredients Limited (Kenya) to supply the OFSP puree processing technology from Proteo International, Italy. SinnovaTek shipped a microwave processor to Kenya in early 2019. SinnovaTek and Euro Ingredients Limited worked together to install the puree processing and aseptic puree packaging equipment (Fig. 5.1).

CIP and Kenya Agricultural and Livestock Research Organization (KALRO) released new OFSP varieties (Irene and Sumaia) in Kenya that have consumer-preferred appearance and processing traits. Dielectric properties of 12 African genotypes were measured at 915 MHz and 2450 MHz in the temperature range of 22–130 °C. Dielectric properties play a significant role in developing commercial processing systems using microwave energy.

5.5 Scaling and Commercialization of OFSP Puree Processing in Malawi and Kenya

Most wheat flour is imported in Africa: 62% in Kenya, and 99% in Malawi. Scaling and commercializing OFSP puree to make baked and fried foods could replace up to 40% of the wheat flour with a cheaper, nutritious, and locally available product. Bakery products are popular across Africa, where many people eat them for breakfast, lunch, and supper. Bread is widely consumed, with diverse recipes. Its enticing flavor and convenience appeal to consumers, enhancing its popularity (Nwosu et al. 2014).

In Malawi, the Tehilah Bakery and Value Addition Centre has played a major role in scaling OFSP puree. Tehilah is a food processing business, established in 2017, that produces nutritious and healthy foods and adds value to locally grown crops. It was founded by Jean Pankuku, a food technologist, following her practical experience in the food industry, especially in the area of new product development and food processing. Tehilah processes OFSP puree in the conventional form (cold chain) and as baked and fried products. The business currently buys fresh roots from over 1000 OFSP farmers in eight districts (Blantyre, Zomba, Chiradzulu, Mulanje, Thyolo, Balaka, Chikwawa, and Nsanje), increasing economic opportunities not just for sweetpotato growers but also for transporters and workers at the bakery. Tehilah substitutes OFSP puree for 40% of the wheat flour in bread and buns. The bakery in Blantyre sells through over 20 outlets there, including Chichiri Shoprite (Fig. 5.3) as well as to Chikwawa district and Lilongwe, the capital city. The bakery plans to add OFSP cookies and various confectioneries to target new markets such as schools, hotels, offices, and manufacturing companies. Tehilah received recognition from the Ministry of Industry and Agriculture for the successful

Fig. 5.3 Tehilah Bakery substitutes OFSP for 40% of the wheat flour in bread (**a**), sold at Chichiri Shoprite (**b**) and elsewhere in Malawi. (Photo credit: J. Pankuku (Tehilah))

Fig. 5.4 Bread made with OFSP on sale at (**a**) Tuskys Supermarket. (Photo credit: CIP) and (**b**) at Naivas Bakery in Nairobi, Kenya. (Photo credit: C. Bukania (CIP))

commercialization of OFSP puree and notable community impacts by creating jobs for women and youths. Other private companies, such as Mother's Holding Limited, are now also actively involved in OFSP puree processing and product development.

In Kenya, Organi Limited has been actively involved in OFSP puree processing for over 6 years. It is based in Homa Bay County; the cofounder and managing director is Ms. Consolata Bryant. The company has established a network of nearly 200 smallholder farmers of whom at least 50% are women and 20% are youths in the western Kenyan counties of Homa Bay, Migori, Kakamega, Busia, Kericho, and Kisumu. The farmers sell OFSP roots to Organi, which makes about 500 kg of puree daily, with the help of 16 employees. The puree is sold to supermarkets (Fig. 5.4) in Nairobi and Kiambu County. In 2017, the company expanded its product line to include OFSP bread and buns with 40% wheat flour substitution. Organi Ltd is planning to gradually increase the number of fresh root suppliers to at least 1000 by 2025 and to extend the bakery section to industrial capacity by June 2022. This will enable the company to expand the range of OFSP products and to sell to more regions. The Kenyan Ministry of Agriculture and the Ministry of Health have recognized the role of OFSP in improving food security and hidden hunger (e.g., vitamin deficiencies) and have added orange-fleshed sweetpotato to the list of foods that are rich in micronutrients (pro-vitamin A-rich carotenoids). The Ministry of Trade and Industrialization took note of the increasing use of OFSP puree and has now developed specifications to facilitate its use in trade and commercial production. Other private companies, such as Euro Ingredients Limited, are now also actively involved in OFSP puree processing and product development.

The commercialization of OFSP puree in Malawi and Kenya has taken relatively similar paths, with both countries managing to penetrate the bakery industry, with beneficial impacts along the OFSP value chain.

5.6 Consumer Acceptance of OFSP Puree Composite Bread

This section describes consumer acceptability of composite bread from OFSP puree. The focus is on bread because it is widely eaten in Africa (Wanjuu et al. 2019; Atuna et al. 2020). Previous studies show that OFSP puree can be blended with wheat flour to bake consumer-acceptable flat or leavened bread (Table 5.2). The composite bread has a superior aroma, color, and soft texture, which contribute to its acceptability. Other benefits include low production costs and improved vitamin A content (Amagloh 2019). Since favorable sensory assessment scores for OFSP-based bread are one of the key drivers for patronage by consumers (Okello et al. 2021), this product has the potential to be scaled in African communities.

5.7 Food Safety in OFSP Puree Processing in Africa

To maintain consumer trust in OFSP products, the puree must adhere to the highest standard of food safety. Understanding the microflora associated with sweetpotatoes is important if processes are to be designed to control growth of spoilage and pathogenic organisms. While the skin of the root is intact, its flesh is protected from microbial attack. However, once the roots are prepared for puree production, the stages of peeling and cutting disrupt the cell structure, releasing nutrients that can be metabolized by microorganisms (Brackett 1994). Bacteria and fungi make up most of the microflora in low-acid, starchy vegetables (Brackett 1987). How the roots are processed determines the microflora of the puree. First, the OFSP roots are boiled or steamed, killing any vegetative organisms present, but allowing spores to survive. One organism that is associated with many types of foods, including root vegetables, and that produces one of the most potent toxins known is *Clostridium botulinum*, an anaerobic bacterium. Vacuum packaging a puree provides the conditions for the spores to germinate and for this deadly toxin to be produced. Cooking/

Table 5.2 Composite breads including OFSP puree and their consumer assessments

Reference	Flesh color of sweetpotato	Form used	Wheat substitution level (%)	Panelist numbers	Results/deduction
Low and van Jaarsveld (2008)	Orange	Puree Flour	38	98 shoppers in 2004 112 shoppers in 2005	Strong preference for composite bread over wheat-only bread owing to its heavier texture, superior taste, and golden color
Wu et al. (2009)	Not specified	Puree	5, 10, 20, and 30	20 students	Incorporating puree led to a relatively high preference for texture and overall acceptability. The 30% blend was the most preferred
Bonsi et al. (2014)	Orange	Puree	10, 20, and 30	192 consumers	Mean acceptability was 6.25 on a 7-point scale, indicative of high consumer preference for the composite bread
Bonsi et al. (2016)	Orange	Puree	40	50 undergraduates	On a 9-point scale, the overall acceptability for the OFSP-composite bread and wheat-only bread is similar. All other attributes had a score of at least 7, indicating high consumer preference
Awuni et al. (2018)	Orange	Puree	46%	310 consumers	Paired preference assessments indicated that 77% of the respondents preferred the OFSP-composite bread over the existing wheat-only one
Ouro-Gbeleou (2018)	Orange	Puree	Not stated	387 consumers	Scores of respondents showed a preference for OFSP-composite bread based on its sweet taste and soft texture
Wanjuu et al. (2019)	Orange	Puree	30%	1024 consumers	Softness, color, taste, aftertaste, smell, and overall acceptability had scores above 7.4 on a 9-point scale, i.e., "very likable"

steaming is crucial for destroying the vegetative organisms, but post-process contamination can allow microorganisms to reenter the product.

A study in a puree processing plant in Kenya found that steaming roots significantly lowered levels of microorganisms but that levels in OFSP puree increased again due to post-process contamination by organisms such as *Staphylococcus* *aureus*, a foodborne pathogen that is commonly found on peoples' skin and noses and in infected cuts (Malavi et al. 2018). Fresh puree, which is currently produced in African countries, requires cold storage. However, refrigerated storage (<5 °C) will allow the growth of organisms that thrive at low temperatures, such as *Listeria monocytogenes*, a bacterium that can cause life-threatening illness in vulnerable groups such as pregnant women, young children, the elderly, and people with suppressed immune systems. Preservatives could reduce the chances of contamination. Adding 0.06% (w/v) of the preservative sorbic acid or benzoic acid while reducing the pH of the puree to 4.2 with citric acid inhibited the growth of *L. monocytogenes* at 4 °C (Pérez-Díaz et al. 2008). Acidifying the puree can also control the growth of *C. botulinum* spores that are unable to grow at pH below 4.5 (Lund and Peck 2000). Acidification and preservatives result in an ambient temperature-stable OFSP puree (Musyoka et al. 2018a).

These studies highlight the importance of strict food safety measures in OFSP puree production. In Kenya and Malawi, official quality standards for OFSP puree have been developed and approved by the respective Bureau of Standards, and it will be worthwhile for other African countries to follow suit. Food safety training not only helps change behavior and attitudes of the OFSP puree processors but also contributes to the safety of the products (Malavi et al. 2021). Food safety and hygiene training workshops were conducted in 2017 and 2019 by CIP-Kenya under the RTB scaling project (Musyoka et al. 2018b). Forty-two participants (22 males and 20 females) attended from national and county government, academia, food processing companies, and nonprofit organizations from different counties. The training aimed to equip participants with knowledge and skills on food safety and hygiene. A knowledge-retention evaluation (questionnaire) held in January 2021 found that the trainees had retained 70% of what they learned at the 2019 course. Food safety regulations and trainings are important components for scaling the production and use of OFSP puree (Sect. 5.9).

5.8 Agribusiness Development and Entrepreneurship Opportunities for OFSP Puree in Africa

OFSP varieties with proven agronomic advantages and acceptance by smallholder farmers (Girard et al. 2017) play a great role in the short- and long-term food and nutrition security in sub-Saharan Africa (SSA). From the supply side, improving the productivity of OFSP is hindered mainly by poor access to quality planting material. Farmers usually recycle their seed, so it is often heavily infected with virus diseases and pests (especially weevils). Consequently, yields are typically only 6 tons per hectare, as compared to the potential 21 ton/hectare (Low et al. 2017). To strengthen OFSP seed systems and improve the nutritional status of children under 5 years of age, several new improved biofortified varieties of sweetpotato have been introduced in SSA since 2014 through partnerships between CIP and national agricultural research institutions (NARIs) (Rajendran et al. 2017).

A strong, entrepreneurial sweetpotato seed system has evolved among NARIs to sustain their seed production and provide a consistent supply of quality, disease-free early generation seed (EGS) from community-based decentralized vine multipliers (DVMs). The DVMs are linked to EGS producers (mainly NARIs) who can supply healthy vines (i.e., free of major pests and diseases, such as sweetpotato virus disease (SPVD) and sweetpotato weevil) (Namanda et al. 2011; Rajendran et al. 2017), and they are sold to farmers or supplied through government extension efforts and projects at highly subsidized prices or free of charge (Okello et al. 2015; Ogero et al. 2016; Bentley et al. 2018). Although most sweetpotato farmers still obtain their planting material from their own or neighboring farms, a market for quality vines, particularly for OFSP varieties, has started emerging in African countries such as Kenya, Uganda, and Tanzania (Rajendran et al. 2017). This has created huge opportunities for NARIs, sweetpotato seed and root growers, and also for processors of OFSP products.

5.8.1 Business Models for OFSP Puree Processing

Five potential business models (Table 5.3) for OFSP puree processing have been identified, and the financial viability has been measured. Medium-scale enterprises were the focus of this study because the puree processing equipment is imported and is too expensive for small businesses. The models were identified through a "financial cost-benefit analysis (FCBA)" using real and hypothetical data on technical and financial operations, collected through key informant interviews from industry players in SSA with expertise in this domain (Rajendran et al. 2019). *Model 1* focuses on OFSP puree processors who also make products such as cookies, cupcakes, and the donut-like mandazi. They store the puree briefly without vacuum packaging, and the goods made from OFSP are sold directly to end users. This is an example of the "business to consumers (B2C)" model. *Model 2* focuses on OFSP puree processors who use vacuum packaging and lots of freezers for storage. Puree is then sold to bakeries. This model is categorized as "business to business (B2B)." *Model 3* focuses on bakers and others who buy OFSP puree from processors. *Model 4* focuses on OFSP puree processors who use preservatives and vacuum packaging rather than cold storage. *Model 5* focuses on OFSP puree processors who make use of the hot-fill technology that improves the shelf life of the puree without any need for preservatives.

All five business models are financially viable in the long run, with the level of average investment between \$30,000 and \$43,000 for medium-scale enterprises. Some key informants said that small enterprises can start with as little as \$1000. However, the sensitivity of the business, net present values, internal rate of return, return on investment, and payback period (the period of time required to recoup a capital investment) for the investments differ across the five business models (Table 5.4).

Table 5.3 Types of potential OFSP puree business models and minimum required investment

Business model	Equipment	Final products	Model	Area required (in square meters)	Total annual investment required (USD)	Maximum capacity of puree requirement and annual production (kg)
1	High fiber puree (HFP) machine, steamer, depositor, baking equipment	OFSP puree, OFSP baked and fried products	B2C	36	$43,030	16,000[a]
2	High fiber puree, steamer, vacuum machine with label printer	OFSP puree	B2B	100	$33,370	375,000[b]
3	Depositor (cookie machine), baking equipment	OFSP baked and fried products	B2C	36	$31,390	16,700[a]
4	High fiber puree, steamer, vacuum machine with label printer, ribbon mixer	OFSP puree	B2B	100	$34,170	375,000[b]
5	Hot fill machine, high fiber puree (HFP) machine, steamer, vacuum machine with label printer	OFSP puree	B2B	100	$37,170	375,000[b]

Source: Key informant interviews (KII) with private players in 2018–2019, author's calculation
[a]Investors buy puree from puree producers, which is a requirement for investors per year
[b]Investors produce puree at a maximum capacity per year

Table 5.4 Financial feasibility indicators for potential OFSP puree business models

Business model	NPV	Internal rate of return (IRR)	Discount rate[a]	Payback period (years)	Return on investment (RoI) per year (%)
1	$291,560	85%	18%	1.3	164
2	$247,018	90%	18%	1.4	198
3	$262,342	90%	18%	1.3	203
4	$265,404	77%	18%	2.8	252
5	$345,380	82%	18%	1.0	266

NPV net present value, *IRR* internal rate of return
[a]Discount rate is based on the 18% lending rate in Kenya

The return on investment (RoI) for each business model is more than 100%, and the payback period is a maximum of 3 years (Rajendran et al. 2019). All five models show good financial viability with different intensities probably influenced by different levels of risk factors. It is important for investors to understand the market demand for the products, available funds, and the type of business model that is appropriate for their resource base and setting. There are two significant risks involved in this business: (1) lack of consistent supply of sweetpotato roots and (2) market demand fluctuation for the product. If marketing strategies are well executed, models 1, 3, and 5 can be the most viable ones. If there are fluctuations in the market demand for the puree product, then investors should focus on model 4 where preservatives are used for producing OFSP puree. Though model 2 is financially viable, it comes with the highest risk for investors.

5.9 Scaling Readiness and Strategy for OFSP Puree in Africa

In order to go to scale, the core OFSP puree innovation requires several complementary innovations ranging from availability of planting material and contract farming to cold chain and extension services. With support from RTB, CIP implemented a scaling project between 2019 and 2021 in Kenya, Uganda, and Malawi. The main objective of the project was to increase the use of OFSP puree in popular baked and fried goods. The approach implemented included the following: (1) identifying smallholder OFSP farmers to be trained on good agronomic practices to ensure the production of high-quality roots; (2) product development training for bakers to substitute up to 40% of wheat flour with OFSP puree; (3) creating income and employment opportunities for youths and women along the value chain; and (4) demand creation through increase in awareness of the nutritional and economic benefits of OFSP puree processing and product development. The scaling project worked with small and medium-sized processors to introduce and expand their use of puree and encourage the development of local supply chains providing high-quality OFSP roots.

The scaling project was backstopped by scaling experts from RTB. It used Scaling Readiness, a stepwise approach for analyzing the innovations from a scaling-out perspective, diagnosing the bottlenecks that hinder scaling out, developing scaling strategies, building common agreements with the stakeholders on the strategies, and updating them accordingly (Sartas et al. 2020a). *Scaling Readiness* breaks down the core innovation into components. *Innovation readiness* is the capacity of the innovation to contribute to development outcomes in specific locations. This is presented in nine stages showing progress from an untested idea to a fully mature, proven innovation. *Innovation use* is the level of use of the innovation or innovation package by the project members, partners, and society. Use begins with the team that develops the innovation and broadens to other users who are

Table 5.5 Summary definitions of levels of innovation readiness and use

Stage	Innovation readiness	Innovation use
1	Idea	Intervention team
2	Basic model (testing)	Direct partners (rare)
3	Basic model (proven)	Direct partners (common)
4	Application model (testing)	Secondary partners (rare)
5	Application model (proven)	Secondary partners (common)
6	Application (testing)	Unconnected developers (rare)
7	Application (proven)	Unconnected developers (common)
8	Innovation (testing)	Unconnected users (rare)
9	Innovation (proven)	Unconnected users (common)

Source: Sartas et al. (2020a)

completely unconnected with the team or their partners. Scaling Readiness is a function of innovation readiness and innovation use (Table 5.5).

Readiness and use levels are evaluated using conceptual, applied, and experimental evidence. Scaling Readiness helps to identify the gaps in the design of the innovations and to prioritize the research and engineering work to address these gaps (Sartas et al. 2020b). The Scaling Readiness framework is discussed in more detail in Chap. 3.

Using Scaling Readiness, the team identified ten complementary innovations, their expected outputs, and overall functions (Table 5.6).

5.9.1 Strategic Partners for Scaling

In Kenya during 2020, partnerships with actors along the OFSP value chain came into their own during the Covid pandemic. Interactions were more virtual than physical, but because of the previous engagement, there was a positive response that ensured farmers continued to benefit through trade. Farm Concern International helped to strengthen these partnerships and develop new ones to ensure that farmers benefitted. Engagement with informal markets facilitated linkages to farmers. Processors and wholesale buyers were engaged to source OFSP roots from farmers. As a result, farmers were in a position to sell more than 33 metric tons of OFSP roots to various market outlets, both for fresh sweetpotatoes and for puree processing, with an estimated value of 1,205,270 KSh ($11,095). The market share for OFSP in the profiled markets increased as more traders and consumers became aware of the benefits of OFSP. Organi Limited increased its database from 139 to 239 contracted commercial root producers, almost doubling the OFSP puree supply to Naivas supermarket. In Malawi, Tehilah Bakery linked buyers to over 1000 farmers in Nsanje, Balaka, Blantyre, and Thyolo districts. In 2021, there were individual farmers who were selling their roots to the bakery as well as associations. Perisha

Table 5.6 Complementary innovations for scaling of OFSP puree in Kenya, Uganda, and Malawi

Innovation profile – OFSP puree					
Complementary innovation	Output 1	Output 2	Output 3	Value chain level	Innovation function
1. Contract farming to provide disease- and pest-free seed	Large OFSP seed multiplication center for seed production	Quality declared planting material law on commercial vine multiplication	Providing incentives and subsidies to commercial vine producers	Planting material	Accessibility (affordability)
2. Processing-friendly OFSP varieties for production by commercial farmers in Kenya	List of processing-friendly OFSP varieties that can be released quickly in Kenya	List of existing OFSP varieties suitable for different climatic areas		Planting material	Accessibility (availability)
3.Delivery of extension services	Training commercial vine producers on vine multiplication and positive selection	Upgrade extension module on disease- and pest-free OFSP production	Commercial OFSP farmer clusters	Planting material	Accessibility (availability)
4. Cold chain for OFSP puree for sales and shelves for shelf-stable puree	Shelves for storing puree before sales to wholesalers and retailers			OFSP puree	Accessibility (availability)
5. OFSP puree processing technologies, equipment for independent processor	OFSP puree packaging equipment			OFSP puree	Capacity to use (hardware)
6. Demonstrations of OFSP puree processing and packaging equipment	Training workshop on OFSP puree business	Guidelines on procedures of puree making	Temporary holding areas for OFSP fresh roots in the processing facility	OFSP puree	Capacity to use (people)
7. Credit access manual for OFSP producers	Credibility assessment guidelines on OFSP production for banks			OFSP roots	Accessibility (affordability)

(continued)

Table 5.6 (continued)

Innovation profile – OFSP puree					
Complementary innovation	Output 1	Output 2	Output 3	Value chain level	Innovation function
8. Advocacy and awareness campaign on benefits of OFSP	Improved awareness along the sweetpotato value chain			OFSP bread or pastry	Motivation (convince)
9. OFSP puree business development models	Manual for OFSP puree business development			OFSP puree	Capacity to use (people)
10. Climate-controlled storage for OFSP roots	Storage facilities for OFSP to reduce postharvest loses			OFSP roots	Accessibility (availability)

Agro and Packaging Enterprises contracted 140 farmers to supply OFSP roots for puree processing as soon as production starts.

Much attention was given to developing the capacity of small and medium enterprises (SMEs) to run competitive businesses that can access credit from financial institutions. In collaboration with NetBizImpact, the project finalized provision of tailor-made business development services to six SMEs – two from Malawi, three from Uganda, and one from Kenya. The six SMEs were Organi Limited (Kenya), Tehilah Enterprises (Malawi), Perisha Agro and Packaging Enterprises (Malawi), Food Biosciences and Agribusiness Innovation Program (Uganda), EADC (Uganda), and BioFresh Ltd (Uganda). The main goal was to offer business solutions that would facilitate economic potential in the OFSP value chain and make the SMEs involved more competitive in the marketplace and achieve scale. During the coaching and mentorship, the SMEs were helped to identify growth opportunities, key constraints, and support to overcome them. NetBizImpact tailor-made business models aimed at enhancing the SMEs' capacity to take advantage of a promising market potential within the OFSP value chain including the puree. SMEs were encouraged to give their feedback on the relevance of the tools and exercises and effectiveness of the coaching and mentoring sessions included in the business development support. Besides coaching, NetBizImpact helped develop quality profiles for each SME, provided tools and templates, did value chain analysis at firm level, and discussed growth plan development. Discussions were held with NetBizImpact to develop a manuscript on the business development service process.

Naivas Supermarket had a 2-day refresher baking training using OFSP puree to retrain Naivas bakers on how to bake with the puree. The training exercise was held with the food safety training exercise. Some samples were collected for nutritional analysis by CIP's Food and Nutritional Evaluation Laboratory (FANEL), and these showed high levels of pro-vitamin A carotenoids.

A cooking demonstration at the University of Nairobi dietetic kitchen (Department of Food Science, Nutrition and Technology) showed how OFSP puree could be incorporated into foods and contribute to dietary vitamin A. This training for kitchen staff explained the benefits of OFSP puree.

In July, the Cleanshelf Supermarket baking team attended a baking training on using OFSP puree where they were trained to bake with puree to encourage the supermarket to start using OFSP puree.

In partnership with DDBio, BBC Africa, under the Life Clinic segment, broadcasted an episode on OFSP work in Africa, creating awareness of the commercial and nutritional benefits of OFSP for a worldwide audience. Euro Ingredients Limited has continued to provide technology demonstrations, equipment support, and trainings on OFSP product development to different partners in both the formal and informal sectors. Recipes for the incorporation of OFSP puree in commonly consumed Kenyan street foods such chapati, mahamri, and bhajia have been developed. In addition, Euro Ingredients Limited has expanded its supply of the OFSP dough and chapati to also include several informal vendors in middle-income sectors in Nairobi.

In Malawi, Tehilah currently produces a minimum average of 200 OFSP loaves of bread per day to a maximum of 560 loaves a day – depending on the capacity and availability of fresh roots. Production is 6 days a week translating to between 5000 and 13,000 loaves a month. A group of women in Balaka were trained to use OFSP puree to make donuts, fritters, and sweet beer (a locally fermented nonalcoholic drink). Over 10 tons of roots (from farmers associations) were supplied to Mothers Holding Ltd, and 12,480 loaves of OFSP bread were produced by mid-2020. The period also saw the setting up of an OFSP puree processing unit and installation of water and three-phase electricity at Perisha Agro, Malawi.

5.9.2 Core and Complementary Innovations for Scaling

The core and complementary innovations were analyzed using the Scaling Readiness approach. In the three implementation countries, delivery of extension services was the most used complementary innovation, while productive varieties were at the highest level of innovation readiness (Figs. 5.5, 5.6, and 5.7). The next highest level of innovation readiness was for processing-friendly varieties and a credit access manual in Kenya (Fig. 5.5), a business development manual in Uganda (Fig. 5.6), and the advocacy and awareness campaigns in Malawi (Fig. 5.7). Many consumers reject the OFSP varieties because they are low in dry matter, but processors preferred these moister varieties. Processing-friendly varieties were still in development in Uganda and Malawi. Financial constraints limited the implementation of cold chain and climate-controlled root storage. OFSP puree business development

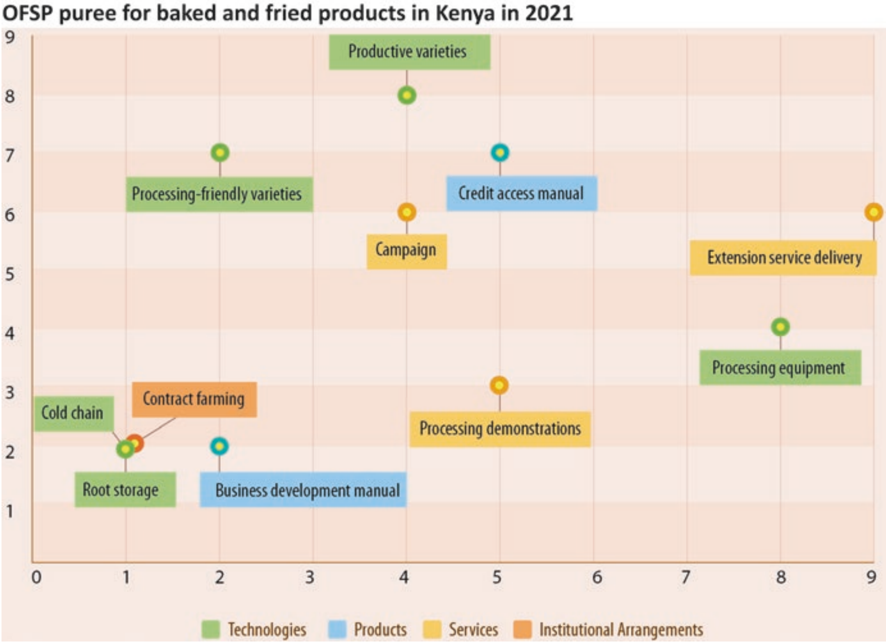

Fig. 5.5 Innovation readiness and use of OFSP puree in Kenya. The *x*-axis represents innovation use, while the *y*-axis represents innovation readiness

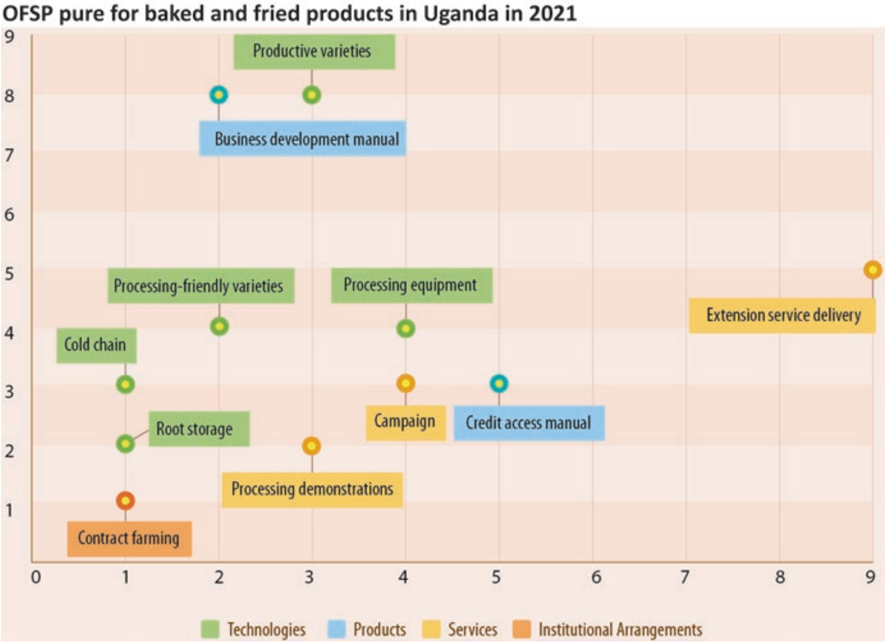

Fig. 5.6 Innovation readiness and use of OFSP puree in Uganda. The *x*-axis represents innovation use, while the *y*-axis represents innovation readiness

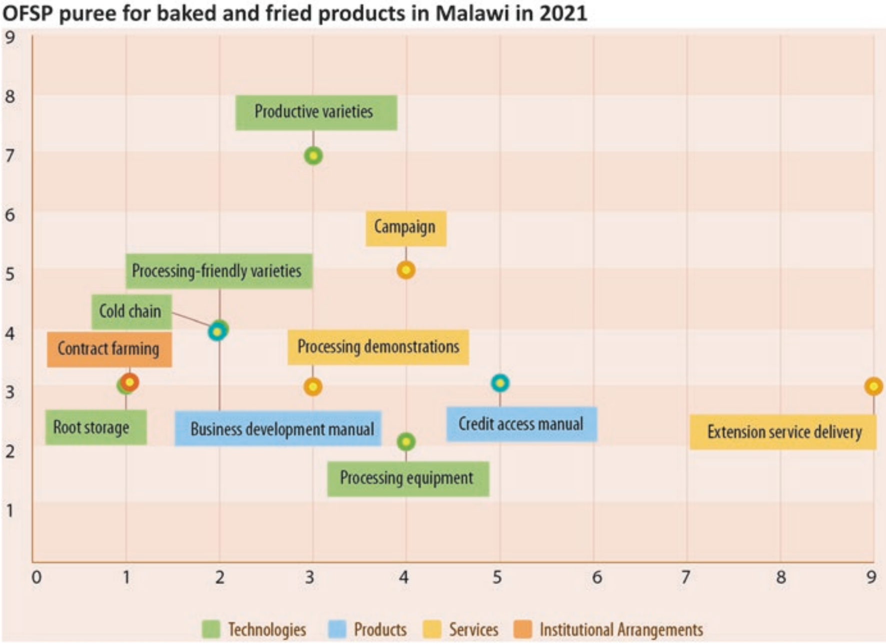

Fig. 5.7 Innovation readiness and use of OFSP puree in Malawi. The *x*-axis represents innovation use, while the *y*-axis represents innovation readiness

manuals were at a high level of innovation readiness in Uganda compared to Kenya and Malawi, while Kenya recorded the highest use of puree processing equipment.

The results highlight some similarities between Scaling Readiness in the three countries and can thus be used as conceptual guidelines for scaling the OFSP puree innovation in other African countries. In addition, they provide guidance on which complementary innovations require more investment to remove bottlenecks.

5.10 Lessons Learned: Moving from Pilot to Large-Scale Commercialization of OFSP Puree in Africa

OFSP puree processing has been successfully piloted in over ten African countries since it was initially introduced with most countries recording steady growth in the demand for OFSP puree-based products. Fresh OFSP puree, which requires cold chain storage, is currently the most common form produced in all African countries. However, the seasonality of the fresh roots poses challenges to the processors. During harvest season, cold storage capacity limits the amount of puree that can be produced and stored in preparation for off-season demand. The need for cold storage also means processors need temperature-controlled transportation to ensure that the puree is supplied to bakeries in good form.

The bakeries typically purchase in small batches to reduce the need for long-term cold storage from their end. This puts pressure on puree processors to continuously increase their cold storage capacity in order to grow their businesses and meet the demand for the nutritious product. To date, the majority of the OFSP processors rely on electricity to power the cold chain storage facilities, which is expensive to maintain in Africa with some regions facing unstable supply, which jeopardizes the quality of the puree. This has been a major bottleneck to scaling the use of OFSP puree in the region. It is this node of the OFSP puree value chain that needs to be addressed in order for large-scale commercialization to become a reality in Africa.

Previous efforts to address the challenges faced by processors included the use of preservatives to eliminate the need for cold storage, which conflicts with consumer preferences. Aseptic shelf-stable puree provides a viable pathway to address this current bottleneck. Yamco LLC in the United States has successfully produced aseptic puree at commercial scale since 2008, supplying the product to various sectors including the bakery industry. Learning from the success story of Yamco, B&B Limited in Kenya has established the first continuous flow microwave system in Africa that is set to commence production of aseptic shelf-stable puree before the end of 2021 (Fig. 5.8). The target market for the product includes large-scale bakeries, restaurants, institutional kitchens, humanitarian organizations for inclusion in nutritional interventions, local governments involved in school feeding programs,

Fig. 5.8 Aseptic puree processing system commercialized by SinnovaTek Inc. under the Nomatic trademark being set up at B&B Limited, Kenya. (Picture credit: Molly Abende, B&B Production Manager)

and informal traders selling street foods, among others. Other countries such as South Africa and Ghana are also in the process of setting up similar systems. Adoption of the continuous flow microwave system in Africa will enable large-scale commercialization of OFSP puree and eliminate the current bottleneck that processors are facing.

5.11 Conclusion

Value addition through processing of agricultural products such as OFSP roots to puree is key to ensuring a stable supply of highly nutritious products to consumers. Puree processing technologies have advanced over the decades from traditional methods involving manual mashing of the cooked roots to highly sophisticated and automated systems such as the fourth generation of continuous flow microwave sterilization systems. To date, steady growth in the commercialization of OFSP puree and the subsequent wheat flour substitution in bakery products has been noted in African countries such as Kenya, Rwanda, Malawi, and Uganda, among others. Positive impacts on revenue generation for small-scale farmers and businesses, employment opportunities for women and youths, and improved nutritional status of target communities are some of the targeted outcomes. These achievements can be attributed to strategic partnerships with stakeholders in agricultural development, public, and private sectors. In addition, financially viable business models have been identified to ensure that OFSP processors make sound financial decisions and maintain a competitive edge in the market. With this rich knowledge base, advanced processing technologies, evidence of Scaling Readiness, and successful piloting of the product, OFSP puree is the breakthrough product for Africa offering the much-needed nutritious products with superior flavor, texture, and appearance accepted by consumers. Further work needs to focus on improving awareness to the multifaceted benefits of OFSP puree along different nodes of the value chain.

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