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Chapter

Appropriate Post-Harvest Technologies for Biofortified Crops Pro Enhanced Utilization, Value Addition, and Micronutrient Retention

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Abstract

Biofortified cassava and sweet potato, targeted for vitamin A deficiency reduction in Sub-Saharan Africa, are highly perishable at post-harvest. Appropriate technologies for processing these crops should primarily be protective of their micronutrients otherwise the purpose of their biofortification is defeated. One of the value-added OFSP root products is the puree, which several techniques have been developed for its consistent quality, preservation and packaging. However, use of aseptic packaging and continuous flow microwave system of rapid sterilization have been reported most suitable, for its high temperatures (≥125°C) and short time principle. For biofortified cassava varieties, post-harvest advances have been on drying, moving from sun drying on bare floor to use of raised platform, solar and mechanical drying. Flash-drying technology is an effective and efficient drying technology that uses rapid heat transfer, which makes it suitable for biofortified cassava. With these advanced technologies, OFSP puree, wet or dried and flash-dried biofortified cassava mash can be targeted for diverse end uses in the food industry-baby foods, jam, pastries, and confectionaries. These technologies, with increased adoption through favorable policies, can enhance availability of diverse nutritious food products, utilization, consumption, and commercialization of locally produced staples, for improved food system transformation.

Keywords: biofortified crops, post-harvest, technologies, value addition, processing

1. Introduction

1.1 Prevalence of malnutrition

The challenge of malnutrition and undernutrition is long-standing globally, with slow progress in interventions despite trends of development; 1.2 billion people lack

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key micronutrients, 151 million children are stunted, 50.5 million children are wasted, while an estimated 2 billion and 38.3 million adults and children, respectively, are overweight or obese [1].

Similar trend with worse statistics has been reported in Sub-Saharan Africa (SSA) as stunted children under 5 years of age increased by just 23% in 24 years (1990–2014) [2]. Millions of people in SSA especially women of child-bearing age and children under 5 years from poor households are deficient in key micronutrients [3, 4]. An estimated 24% of all child deaths are due to vitamin A deficiency, out of which 48% are preschool-age children [5].

The consequences of vitamin A deficiency include a high risk of diseases such as diarrhea and measles, growth retardation, and premature death for children under 5 years of age, weakened immune system, visual impairment, and blindness [6].

1.2 Interventions on micronutrient malnutrition

Efforts to address micronutrient malnutrition using both nutrition-specific and sensitive interventions have been reported especially in SSA. On nutrition-specific interventions, there has been significant support for exclusive breastfeeding (EBF), improved Infant and Young Child feeding (IYCF) practices, micronutrient supplementation, treatment of severe malnutrition with Ready-to-Use Therapeutic Foods (RUTF), mandatory large-scale fortification of selected foods (salt, sugar, oil, and flours), and Home-Grown School Feeding in some developing countries [7]. Nutrition-sensitive agriculture, mainly biofortification, and water, sanitation, and hygiene (WASH) programs have been appreciably promoted under nutrition-sensitive interventions.

However, each of these intervention programs has its limitations, which inhibit impact at scale and sustainability. For instance, women have so many reasons for not practicing exclusive breastfeeding. Micronutrient supplementation programs are mainly funded by external donors with unguaranteed sustainability, and so unable to meet the set goals of the international health organizations. Other limitations include poor access of the poor people to markets, health-care centers, and other places where the supplements are available, as well as lack of public enlightenment on the health benefits of these nutrient supplements [8, 9]. For large-scale food fortification, being a food-based industrial approach for addressing micronutrient malnutrition, and expected to cover a wide population, has so far been largely limited in reaching most rural dwellers. The coverage of fortified foods is dependent on how developed the market infrastructure is, and most rural poor have poor access to market where the fortified foods are [7]. In Nigeria, locally processed and unfortified foods are often more readily available and affordable to the poor rural dwellers who need fortified foods more because of their poor diets. Worst still, some of the industrially produced food vehicles that are expected to be adequately fortified are often times either not fortified at all or not adequately fortified [10].

Poor knowledge of nutrient contents of many indigenous foods hinders promotion and practice of dietary diversification and nutrition-sensitive food production system. Nutrition education as a strategy is yet to reach an impactful scale on behavioral change [7].

Biofortification, therefore, came up as a sustainable agricultural-base complementary approach to address micronutrient malnutrition in developing countries, targeting the vulnerable populations.

2. Biofortification

Biofortification is the process of breeding staple crops to have higher contents of essential nutrients either through selective breeding or genetic engineering [11]. It is a cost-effective, and sustainable technique of delivering essential micronutrients to populations whose major food crops are deficient in them, and that have limited access to diverse diets and other micronutrient interventions. Biofortification is a globally recognized agricultural-based approach to addressing hidden hunger and food insecurity, especially in the SSA. Biofortification of staple crops, being within the agricultural sector, presents exceptional investment opportunities for addressing this national priority through production, processing, and marketing of diverse and more nutritious crops that can sustainably improve the nutrition status of vulnerable populations. It is cost-effective because the only major cost required is that of initial breeding and introduction; once biofortified crops are in the farmer food system, they can reach remote, rural populations that are difficult and expensive to reach with regular supplementation promotions [12–18]. According to Garg et al. [19], biofortification delivers food crops with improved key micronutrients—iron, zinc, and provitamin A that are usually lacking in the diets of the developing world. International initiatives, such as the HarvestPlus and national programs, are available to achieve these targets and so far, they have delivered crops with the potential to increase the quantity and quality of essential micronutrients in human diets, especially in staples like wheat, maize, cassava, beans, sweet potatoes, and millets [19].

Biofortification has enabled a shift in agricultural system from "increasing crop yield and productivity," which has resulted in a high rise of micronutrient-deficient food crops to "producing nutrient-rich crops in sufficient quantities," which will help address micronutrient malnutrition, especially in the developing countries [20].

2.1 Biofortification techniques

Biofortification techniques can be transgenic, conventional, and agronomic approaches, using biotechnology, crop breeding, and fertilization strategies, respectively. The three approaches have been targeted for cereals, some legumes, and vegetables (rice, wheat, maize, sorghum, common bean, potato, sweet potato, and tomato) while some crops could only be achieved by one or two of the techniques. However, more crops have been targeted by transgenic approach, but in practice, conventional breeding technique has been the highest [19].

To date, more than 400 biofortified varieties of 12 crops have been released in over 40 countries, facilitated by HarvestPlus and CIP that is exclusively on biofortified sweet potato varieties [19]. **Table 1** shows biofortified crop varieties of sweet potato available in some countries [21].

2.2 Biofortified crops

Some common staples in Africa have been successfully biofortified with provitamin A (cassava, maize, and sweet potato), beans with iron as well as sorghum and millet with iron and zinc. Biofortified cassava and sweet potato are gradually growing in awareness and adoption in Nigeria and other parts of SSA where they are staples, to address vitamin A deficiency. Biofortified crops with increased contents of essential micronutrients are delivered to consumers through the same familiar traditional practices by the key actors of the value chain, thus reaching the target populations

Countries	Orange-fleshed sweet potato	Countries	Orange-fleshed sweet potato
Uganda	Ejumula	Tanzania	Carrot C
	Kakamega		Mayai
	Vita (Naspot 90)	Nigeria	UMUSPO3-Mothers Delight
	Kabode		UMUSPO1-King J
	Naspot 12O		UMUSPO4-Solo Gold
	Naspot 13O	Zambia	Twatasha
Malawi	Zondeni		Kokota
	Ana Akwanire		Chiwoko
	Chipika		Zambezi
	Kadyaubwerere	Mozambique	Gaba gaba
	Kaphulira		Persistente
	Mathuthu	USA	Jewel CIP440031
Rwanda	Gihingumukungu		Resisto CIP440001
	Ndamirabana		W-151 CIP440005
	Vita		Caromex CIP440136
	Kabode		Kandee CIP440140
	Terimbere		LOS-323 CIP440185
	Cacearpedo		Cordner
Kenya	Kakamega IP441768		W-119
	K566632		

Source: Kapinga et al. [21]. Catalog of orange-fleshed sweet potato varieties for SSA.

Table 1.
Orange flesh sweet potato available/released in some African countries and USA.

of undernourished and low-income groups that have limited access to diverse diets, supplements, and fortified foods [7].

2.2.1 Biofortified versus non-biofortified crop varieties

The principle of biofortification is to nutritionally improve the existing regular staple crops without altering the traditionally known identity of the crops. No significant differences are expected, rather improvement in all the attributes of biofortified cassava, sweet potato, and white maize compared to those of their non-biofortified varieties except for orange (sweet potato) or yellow (cassava) color, which is indicative of the beta-carotene present. For biofortified millet and sorghum, which are biofortified with iron and zinc, there is no difference in the physical traits between the two breeds except that their micronutrient contents, precisely iron, and zinc are higher in the biofortified ones. However, biofortified cassava, maize, and sweet potato have been reported to have less dry matter (more moisture content) and so softer in texture than the non-biofortified varieties. Breeders are working on these so that they can match up with the regular non-biofortified varieties, to boost farmers' adoption and consumers' acceptance. Improvement on biofortified varieties of the crops is being geared towards increased dry matter and recently released varieties like "solo gold" variety of OFSP in Nigeria has higher dry matter content. Every new variety released is an advancement on the former one, based on micronutrient concentration as well as farmer and consumer-preferred quality traits especially yield, drought tolerance, and resistance to pest.

2.2.2 Cassava—overview

Cassava is a major vegetable root staple in several countries of Sub-Saharan Africa, Latin America, and Asia. Of all root crops, it is the most important crop in Africa [22]. The world production of cassava is estimated at 242 million tons, out of which 54% (130 million tons) is produced in Africa, and 52% (68 million tons) of it from west Africa alone [23]. Nigeria is the number one producer of cassava in the world with an annual production of 59 million tons in 2019, followed by the Democratic Republic of Congo, 40 million tons. Ghana is the third African producer with an annual production of approximately 22.4 million tons [24, 25]. In terms of calorie contribution, cassava is the number three source of calories in the tropics [26], with about 500 million people relying on it for at least 10% of their daily caloric intake. In West Africa, cassava is a major source of carbohydrates in human diet, a well-placed, relatively cheap staple crop in developing countries as tpulp is an important source of energy with a calorific value of 250 kcal ha^{-1} day^{-1} [26]. However, cassava, which is mainly grown for its starchy tuberous roots and is a valuable source of cheap calories for low-income earners has now gained a strategic position in world trade. Besides its direct use as food, cassava is also used as a livestock feed and a raw material in the production of starch, tapioca, and snack foods [27]. As food, it can be boiled or roasted for consumption or can be milled into flour and used in making common dishes such as *Ugali* in East Africa as well as *garri* and *fufu* in West Africa. Dried cassava chips have varied applications by end users like breweries, confectionaries, starch, and flour for food. The crop is now produced for food and income, traded in different forms targeting diverse end uses; cassava flour, dried cassava chips, and raw cassava. In Uganda, 200,000 MT of cassava flour is consumed per annum, with most of it being traded in traditional informal markets [28].

2.2.3 Biofortified cassava (yellow cassava or vitamin A cassava)

Cassava is one of the staples targeted for biofortification as it is consumed daily by populations in some SSA countries like Nigeria, Ghana, Cameroon, Sierra Leone, Uganda, and DR Congo. Biofortified (vitamin A cassava) or yellow cassava is a relatively new breed of cassava that is rich in beta-carotene for improved nutrition of the consumers. In the African continent, it is being used as a vehicle to alleviate vitamin A deficiency through its biofortification with provitamin A (beta-carotene) by HarvestPlus in collaboration with International Institute of Tropical Agriculture (IITA) [19]. Under these collaborations, six biofortified provitamin A cassava varieties have been released in Nigeria namely; TMS 01/1368—UMUCASS 36, TMS 01/1412—UMUCASS 37 and 2014; TMS 01/1371—UMUCASS 38 and NR 07/0220—UMUCASS 44, TMS 07/0593—UMUCASS 45, and TMS 07/539—UMUCASS 46) and one in the Democratic Republic of Congo (Kindisa [TMS 2001/1661]) [19, 29, 30]. The yellow cassava varieties are similar to those of white in all attributes except for the color, which is an indication of its biofortification with beta-carotene. They are also high-yielding and resistant to many pests and diseases.

2.2.4 Sweet potato—overview

Sweet potato is an important root crop globally, with an annual production of 112.8 million tons in 115 countries in 2017, and China is the leading producer, followed by Nigeria with 3.9 million metric tons per year [31], Tanzania, Indonesia, and Uganda [32]. In recent times, although SP production and consumption have significantly increased in Africa, Asia, South American continents, and Caribbean islands, it is more profusely grown in Africa. International Potato Center (CIP) [33] reported that sweet potato is the third important food crop in seven central and eastern African countries, fourth priority crop in six South African nations, and eighth in four West African countries. SP, which is known as a food security crop due to its low agriculture input requirements [34], is recently changing to a significant cash crop. Sweet potato is a versatile crop that serves the roles of food and nutrition security as well as cash crop in both raw and processed forms. SP is an important root crop that can thrive in marginal soil with wide agro-ecological adaptability. In Nigeria, it can grow in all 36 states of the country plus the federal capital territory. It has a short maturity period of 3–4 months while its roots and vines are used for both human and animal consumption [35]. Sweet potato roots contain various kinds of physiologically functional components such as polyphenolics, anthocyanins, fibers, and carotenoids.

Value addition of sweet potato roots with these functions has resulted in their commercial utilization as an ingredient in confectioneries, noodles, alcoholic drinks, and beverages [36]. All varieties of SP are good sources of vitamins C, E, and K, several B vitamins, and the key minerals of magnesium and potassium. The leaves have appreciable levels of protein, and are widely used in the dairy industry in East Africa. It is a source of livestock feed with great potential as an industrial raw material.

2.2.5 Biofortified sweet potato (orange-fleshed sweet potato)

Orange-Fleshed sweet potato is a breed of sweet potato that is additionally rich in beta-carotene, a precursor of vitamin A through biofortification using conventional breeding practices, and drawing on the rich genetic diversity of sweet potato. OFSP is a proven, effective, and sustainable source of vitamin A, significantly contributing to the fight against vitamin A deficiency (VAD) in Africa [37–39]. Just 125 g of boiled OFSP roots can meet the daily recommended intake levels of vitamin A for a child. The orange color of OFSP shows the concentration of beta-carotene present; the deeper the orange color of the root flesh, the more the beta-carotene content present. OFSP as a staple food can serve as a cheap and sustainable source of Vitamin A in developing countries, where malnutrition is a big problem, and are growing 95% of the world's sweet potato crop. OFSP also contains antioxidants that help prevent degeneration of cells, as well as natural sugars, which are slowly released into the bloodstream, thus ensuring a balanced source of energy, without spikes in blood sugar that is associated with fatigue and weight gain. It again has vital, life-promoting phytochemicals that enhance protection from peroxides [40].

HarvestPlus and International Potato Centre (CIP) have developed and released several varieties of orange sweet potato with high vitamin A across sub-Saharan Africa. In Nigeria, three OFSP varieties are available namely; UMUSPO3-Mothers Delight, UMUSPO1-King J, and UMUSPO4-Solo Gold [35]. In Uganda, six varieties have been released, namely; Ejumula, Kakamega, Vita, Kabode, Naspot 12O, and Naspot 13O); and three in Zambia (Twatasha, Kokota, and Chiwoko). Zambia

Agriculture Research Institute has successfully completed the development of 15 new varieties of vitamin A fortified sweet potatoes [41].

OFSP is widely consumed as a vegetable dish (boiled, fried or roasted) as well as in different products through processing and value addition for improved household food intake. These include pastries, beverages as well as enriching existing indigenous foods, which are described in details by Phorbee et al. [35]. OFSP products can also be a source of income as they can be commercialized at all levels for income generation, job and wealth creation for all especially women and youths.

2.2.6 Carotenoids in biofortified sweet potatoes and cassava

Carotenoids are well known for their health-promoting benefits, which include immune boosting and reduced risk of developing some non-communicable degenerating diseases like cancers, cardiovascular diseases, cataracts, and mascular degeneration [42]. Carotenoids are made up of many other components that result in provitamin A activity. These include alpha-carotene (α-carotene), beta-carotene (β-carotene), beta-cryptoxanthin, Lutein, zeaxanthin, and lycopene. Among the carotenoids, α- and β-carotenes have a high provitamin A activity [42]. Orange fleshed varieties are appreciably rich in proVitamin A [43] with some having as much as 8000 μg β-carotene per 100 g of fresh weight while some Kenyan varieties have reportedly yielded 1240–10,800 μg per 100 g of fresh weight. However, carotenoids are known to be thermal and photo sensitive as they undergo degradation when exposed to heat and light, [44] and also through some processing techniques like cooking [45]. There is, therefore, the need to process OFSP with techniques that minimize carotenoid loss, so as to achieve the purpose of its biofortification.

Yellow cassava varieties are being grown and disseminated in many West African countries especially Nigeria, for their high concentrations of beta-carotene and being used to fight vitamin A deficiency. According to Harvestplus, yellow cassava can provide up to 100% of daily recommended vitamin A intake for women of reproductive age and children when eaten regularly [46]. Since cassava is a major part of many people's diets, introducing cassava bio-fortified with vitamin A is an excellent innovation and a significant contribution towards improving the food system transformation in the SSA.

2.2.7 Biofortified maize

Maize is a versatile cash crop grown for food, feed, and industrial purposes (an important source of sugar, oil, starch, and ethanol). For example, corn starch is an important raw material in pharmaceutical, food, and textile industries. The diverse end uses of maize globally have informed the basis for breeding higher yielding varieties of maize. Further research on maize has also led to the discovery of varieties that are naturally high in beta carotene contents, which HarvestPlus uses to breed high-yielding varieties of biofortified maize. These varieties have higher contents of provitamin A, which are being used to fight vitamin A deficiency is a major output in biofortification. In Zambia, three PVA maize varieties have been commercially grown namely, GV662A, GV664A, and GV665A. Also in Nigeria, four varieties have been released out of which two are hybrid; Ife maizehyb-3, Ife maizehyb-4, and 2 open pollinated varieties-Sammaz 38 and Sammaz 39 while one OPV CSIR-CRI Honampa has also been grown in Ghana since 2013 [47]. Malawi, Zimbabwe (ZS242) and Tanzania have also released PVA maize recently [48]. In a study conducted among Zambia, an increased pupillary response was observed among children who consumed PVA maize [48]. Breeders have also assessed antioxidants like tocochromanols, oryzanol, and phenolic compounds in PVA maize, which are health-beneficial [49].

2.2.8 Biofortified sorghum and millet

The prospects of breeding for micronutrients and beta-carotene rich sorghums have been discussed by Reddy et al. [50]. ICRISAT has successfully bred and released five lines of iron biofortified varieties of sorghum in India and two in Nigeria. Three of the Indian lines are hybrids (ICSA 661 × ICSR 196, ICSA 318 × ICSR 94, ICSA 336 × IS 3760) while two non-hybrid (ICSR 14001, ICSH 14002) and those in Nigeria are 12KNICSV-22 and 12KNICSV-188 whose iron content is three times higher than typically grown sorghum. The iron biofortified varieties of sorghum are bred and targeted at boosting iron intake of the malnourished populations especially northern Nigeria where sorghum is a staple cereal with relatively high production and consumption. These new varieties involved crossing local Nigerian germplasm with improved lines from ICRISAT (Mali).

Pearl millet is reportedly the cheapest source of iron and zinc [51] and large variation has been seen in its germplasm for these micronutrients [52]. In India, ICRISAT has also released iron and zinc biofortified pearl millet variety "Dhanashakti" and a hybrid ICMH 1201 (Shakti-1201). Many other commercial varieties and hybrids containing high content of iron and zinc have also been reported [52, 53].

3. Perishability of root and tuber biofortified crops at postharvest

Postharvest losses of food crops are traced to history especially in the tropics where the temperature is relatively high. This is a big challenge in the agriculture sector as over one-third of produce is lost after harvest [54] before they reach consumers. The losses, both physical and biological are due to poor management of the produce along the value chain, which are poor packaging from field after harvest and use of inappropriate packaging materials, transportation, poor handling in marketing and display of produce for sale, exposure to heat and sunlight, which subject fruits to undue ripening, lack of good storage facilities and conditions prior to sales. Generally, the key actors of agricultural produce (producers, wholesalers, and retailers) in the SSA lack capacities and facilities to maintain highquality and safe perishable plant produce from farm to table [55]. Losses of perishable crops have implications on quality, quantity, market value, and safety of the produce. According to RAS (2015), insufficient and poorly maintained transport and market infrastructure for handling food products in both urban and rural areas have frequently resulted in high level of waste and spoilage [56].

OFSP and VAC crops, like the non-biofortified varieties are perishable after harvest. Fresh sweet potato having relatively high moisture contents are very sensitive to microbial spoilage, even at refrigerated conditions, hence they must be consumed within a few weeks after harvest or be processed into various products. Cassava can barely stay for 48 hours post-harvest before physiological deteriorations start. Also, cassava roots are bulky and therefore transportation from farm to market or other destinations within the value chain can be challenging in term of cost and stability, thus reduced quality, quantity, and market value. More so, most of the farmers are small holders who harvest manually so the roots are at risk of bruises, which stress and damage the roots. Also, during packaging and transportation, skin of the roots could remove, causing more bruises to the root and opening them up for rapid spoilage [57]. The packing sacks are also often times over filled with the crops, which can further impair the roots.

4. Postharvest technologies for enhanced shelf stability and nutrient retention

To manage postharvest losses, processing is very essential to preserve the crops as well as add value to the crops for food product diversity and improved commercial competitiveness.

4.1 Postharvest utilization and processing of OFSP

4.1.1 Utilization

The high content of provitamin A, which is important to health in OFSP has enhanced its utilization in processed forms like diced, mashed, or pureed OFSP. In school feeding program, OFSP in puree or other forms has been added to school menu in some countries like US, Nigeria, Ghana, etc. to boost the nutritional quality of those meals. CIP research has shown the importance of OFSP puree in bakery as it has been able to develop an acceptable OFSP puree-wheat flour composite bread in which 45–50% is OFSP puree. The bread is not just rich in pro-vitamin A but also cut down on quantity of sugar and oil in the formula while reducing use and dependence on wheat flour, which is often imported in some Africa countries, thus cutting down production cost significantly. The OFSP puree-based products are healthier as they retain more nutrients especially pro-vitamin A. Sweet potato purees and powders can also be used as thickening and gelling agents to impart desired textural properties, and at the same time enhance the nutritional values, antioxidant activity as well as natural color (e.g., orange and purple) of many food products. With increased urbanization, there is growing demand for convenient and healthy foods, which sweet potato purees can easily fit in as functional ingredients in processed foods. More so, the novel advancement of processing OFSP puree aseptically with continuous flow microwave heating, is an opportunity for industries to produce nutrient-rich and shelf-stable puree for institutional use in social protection programs.

Sweet potato is a major root crop utilized widely for diverse food products as well as feed and industrial products. As food, sweet potato roots (both orange and white fleshed) are mainly consumed domestically as boiled or fried. In Kenya, 90% of the sweet potato produced is used domestically as food. Use of vines as fodder and leaves as a vegetable is common in some parts of Western Kenya [58].

4.1.2 Processing of OFSP and products

Despite the importance and knowledge of the nutritional benefits of OFSP, it remains generally underutilized, possibly because the roots are perishable, which reduces their market value. Fresh sweet potato is eaten boiled, steamed, roasted, or fried in most African communities [59], so processing OFSP roots into products create more options for consumption, improve availability, and reduce losses. The fresh roots of sweet potato contain high moisture content (50–70%) and thus relatively low mechanical strength. They also have a very high respiratory rate, which generates heat that aids softening of the roots, and eventually leads to damage. The shelf-life of sweet potato roots varies from few days to months depending on the cultivar and storage conditions [60]. SP storage roots are subject to several forms of postharvest losses right from harvesting, transportation from farmers' field to market and storage. These are due to mechanical injuries, weight loss, sprouting, diseases, and pests [61]. Since sweet potato does not stay for long after harvest, there is a need for processing and value addition. Also, for diversity in use/consumption and commercialization, sweet potato is processed in various ways, using various techniques, which include cooking, fermentation, and drying. Cooking could be boiling or frying, roasting/baking of the roots while other techniques, either single or multiple, result in the development of other value-added food products for household consumption and/or income generation [35].

Processing or value addition, as a way of diversifying utilization of SP is greatly dependent on the roots' cultivars. SP cultivars' screening, targeting diverse end uses is an important activity in processing and value addition because not all SP root varieties are suitable for all end products. CIP and other related research institutions nationally and internationally test SP cultivars' suitability for diverse end uses. They develop the best food products from different cultivars of SP, promote and transfer the technologies to local farmers and processors. In some cases, they scale up the technology transfer by partnering with selected private companies (medium-large scale).

Postharvest processing of sweet potato involves primarily grading, sorting, peeling, cleaning, etc., and secondarily product making. Sweet potato processing technologies into puree and other forms are available in various parts of the world so that they can be used as functional food ingredients in many food products. The processing operations involved in these technologies and their effect on quality, storability, nutritional values and rheological properties of SP purees and powders/flours have been reviewed by Truong and Avula [62].

Available processing technologies at all levels are the key drivers of promoting SP production and consumption. All parts of SP are useful in product making; the roots can be processed into chips, crisps, flakes, flour, granules, starch, and alcoholic beverages [63]. Also, the leaves, into powders and used as functional ingredients in food products like ice cream, juices, tea drinks, and bread due to their high phenolic content and antioxidant activity [64]. In many of the SSA countries, SP has been processed into intermediate and/or finished product [63] to make both traditional and novel OFSP-based products. Some traditional foods have even been enriched with OFSP, because of its high beta-carotene content. In Uganda, an array of novel and traditional food products has been made from OFSP, namely composite flours, chapatti, mandazi, juice, bread, doughnuts, and other confectionary products. Traditional ones, which are produced by the local farmers are pit stored tubers, *Amukeke* (dry white slices), *Inginyo* (dry chips, chunks), *Amukeke* flour and *Inginyo* flour [65]. Also in Kenya, sweet potato processing is reportedly processed into different traditional products like *mandazi bhajia*, among others [58]. In Nigeria, Phorbee et al., [35] produced a recipe book on OFSP and VAC as household guide for processing the two biofortified crops into various nutritious foods. OFSP has also been used to improve carotenoid contents of some Nigerian indigenous foods. One such is the use of OFSP as a functional ingredient in making a local beverage called *Kunu* (a popular local cereal-based beverage) where it serves as both sweetener and nutrient enhancer. Others are like OFSP-enriched *Amala, fufu*, semolina, pap, etc. Although mainly at household level and micro/small to medium processing scale, OFSP has also been processed into intermediate products like chips, flour, and puree to make finished OFSP-based pastries (chin-chin, puff-puff, doughnuts, buns, etc.) and confectionaries to increase market options for sweet potato products.

The processing technologies are usually developed by the national and international institutions, and then transferred for adoption, to local NGOs, community health workers, women, and youth groups directly or through training of Trainers.

4.2 Puree overview

Purée is a cooked food, usually from vegetables, fruits, or legumes, that is ground, pressed, blended, or sieved to a creamy consistency [66]. It is usually a very smooth lump-free food made from a specific food, which the puree is named by, for example, applesauce, mashed potatoes, or tomato purée. Pureed foods are easier to digest as pureeing is like chewing, with the food partially broken down and easier for the system to absorb. Pureeing can be done manually or mechanically. Manual pureeing, depending on the food, can be achieved by simmering, boiling, until it is very soft and then, mashed with a fork or ladle, for example, potato. It can also be done by pushing the food through a strainer, or crushing it in a container until smooth and even in consistency, for example, banana. Pureeing can equally be done using a blender, food processor, or food mill, for example, tomato. However, purées generally should be cooked, either before or after grinding, to remove contaminants, reduce moisture, improve flavor and texture.

4.3 OFSP puree

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. OFSP puree is an ingredient in many foods, including baby foods, casseroles, puddings, soups, pies, cakes, ice creams, breads, and other products [36, 67–69]. Sweet potato purees are also used in fruit/vegetable-based beverages and restructured products as well as commercial ones like jam, ketchup, flakes, and powders while various fermented food products have also been explored [36, 70–74].

OFSP is naturally sweet and when used in baked goods and confectionaries, there is a reduction in the sugar, fats, and oil used thus more nutritious and healthy foods for less cost. With the efforts of CIP in many developing countries, adoption of OFSP puree has empowered women and youths in developing new OFSP-based food products and created opportunities for income generation along the value chain. Farmers are becoming more confident to grow OFSP because there is market for it while puree processors are encouraged to process because there is demand for it. For instance, in Kenya alone, demand for OFSP puree is valued at more than USD 5 million annually. Creating demand for OFSP has increased the crop's market value, encouraging more farming households to grow and consume it, while making pro-vitamin A products available to consumers [75]. Similar trends are found in other African countries like Ghana, Tanzania, Rwanda, Nigeria, and Uganda although no available data on the market value.

4.3.1 Puree technology for OFSP processing

Use of puree is growing in bakeries, eateries, and restaurants globally [76] and its technology from sweet potato has been developed in industrialized countries like USA since the 1960s [77, 78] as well as in developing countries, especially Africa since the 1990s. OFSP puree processing technologies have advanced over the decades from traditional methods of manual mashing of cooked roots to highly sophisticated and automated systems.

Several techniques have been developed for puree processing in order to produce purees with consistent quality, despite variations in carbohydrate content and starch degrading enzyme activities due to cultivar differences, and postharvest handling practices [67, 79]. Process operations for pureeing of sweet potato include washing, peeling, hand-trimming, cutting, grinding, pre-cooking/finish-cooking. The cooking temperature-time must be programmed to suit the enzymatic starch conversion in order to produce puree with desired maltose levels and viscosities. For SP puree that are thermally processed, the starch is gelatinized and produces thick slurry puree with cooked feel that may not be acceptable in juicy products. This is a limitation to the heat treatment technology of SP puree but fortunately overcome with an alternative approach of grinding the raw sweet potato and treating with acid to inactivate oxidizing enzymes during juice extraction. At the same time, the ungelatinized starch and flour with high dietary fiber can be recovered as other by-products from this alternative process [80]. **Figure 1** shows the schematic representation of SP puree processing with all the unit operations highlighted for puree preserved by both freezing and use of preservative. Raw sweet potato roots are peeled either by abrasive rollers or steam flashing, followed by thorough washing, trimming, and cutting into slices, strips, chunks, or dices. The cut roots are steam cooked and then passed through a pulp finisher to make the purees. The peeled sweet potato roots are cut into desired shapes with specific sizes recommended by Walter and Schwartz [81]; For cubes, it is 2 cm; strips, 2 × 2 × 6 cm; and slices, 0.5–0.95 cm thickness or mashed using a hammer mill with rotating blades to chop and push the materials through a 1.5–2.3 mm mesh screen [81]. The cut or mashed roots are then steamed blanched at 65–75°C to activate the amylases and gelatinize the starch for hydrolysis. For the sliced, striped, and cubed roots, hammer mill is used to pulverize the blanched materials into puree. For puree that targets high maltose content, the blanched puree is pushed into a surge tank and hold at 65–75°C for more starch hydrolysis [68].

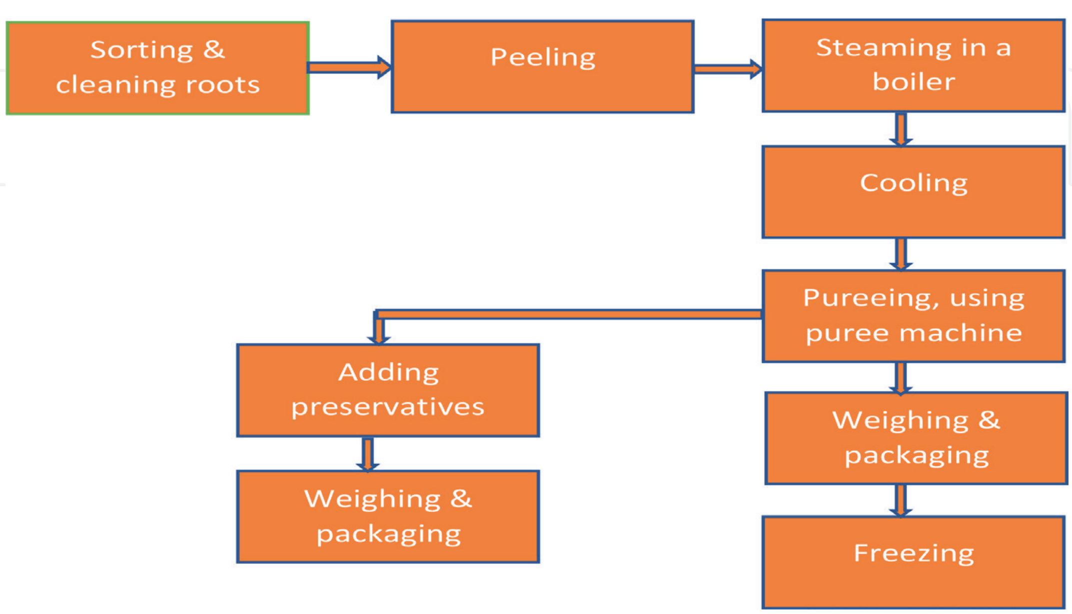

Figure 1.
Flow chart of OFSP Puree processing. Adapted from Owade et al. [95].

Hoover and Harmon developed another technique called "enzyme activation technique" for processing sweet potato puree [82, 83]. The technique, which is now commonly used in food industry uses endogenous amylolytic enzymes to hydrolyze starch in sweet potato to process the puree.

SP puree can be further processed and used in other forms for various purposes in food industry. SP flour from puree can be made by drying while extrusion technology and chemical treatment are explored for specific use of the flour. Drying of SP puree can be through high-tech drum or spray drying but in many African countries, solar and mechanical drying in cabinets is common in producing sweet potato dried chips which are then milled into flours [84, 85]. For OFSP flour from puree, choice of drying technology is important, technologies that retain the provitamin A should be the priority so as not to defeat the purpose of its biofortification. Change of flour color from orange to white after drying is an indication of carotenoid loss to drying, which should be avoided as much as possible by choosing technologies that prevent prolonged exposure to heat and sunlight. With high level of carbohydrate, Β-carotene (orange-fleshed varieties), and anthocyanin (purple-fleshed varieties), SP purees and dehydrated forms can be used as functional ingredients to impart desired textural properties and phytonutrient content in processed food products [62].

Fermentation (bio-processing) of OFSP is another processing technology that can produce functional foods and beverages such as sour starch, lacto-pickle, soy-sauce, acidophilus milk, etc. through either solid-state or submerged fermentation [86]. These foods are opportunities to diversify OFSP utilization options, increase use and consumption as well as commercialization for improved health and wealth.

4.3.2 Puree technology for OFSP preservation and packaging

Purees processing technologies go hand in hand with preservation and packaging, which are achieved by various methods namely; low temperature storage (refrigeration and freezing), canning, aseptic packaging and chemical treatment of puree for prolonged shelf-life over its supply chain.

The finish-cooked puree can be packaged in can to produce a shelf-stable product or in plastic containers for a low-temperature storage (refrigeration or freezing) [79, 86, 87]. However, each of the two preservation approaches has its constraints in puree processing. For canning, in as much as it does not require special storage facilities and conditions, the finished product is prone to some sensory (flavor, texture & color) and nutrient degradation. This is because the canned SP (a low-acid food, pH 5.8–6.3) puree is subjected to high conductive heat treatment for a long time (e.g., 165 minutes at 121°C for an institutional #10 can size). On the other hand, if the sterilization is done through slow rate of heat transfer from the wall to the center of the can, there is a limit to the can size and number that can be produced, which again restricts production capacity of the industry and availability of SP puree for use as a food ingredient.

Also freezing, which is a long-known preservation technique with relatively less sensory and nutrient degradation is capital intensive in term of energy, storage space, distribution logistics. It has restricted product package sizes and above it, the puree has to be defrosted before use, which is not user-friendly. With these limitations, few food companies are into commercial production of canned and frozen puree even in developed countries and almost none in the SSA countries [84].

However, to address the limitations of canning and freezing in producing high quality shelf-stable purees, aseptic packaging and continuous flow microwave system for rapid sterilization are being used [62].

Aseptic processing uses the principle of high temperatures (≥125°C) short time (HTST) to produce a higher quality puree with comparable level of microbiological safety as that of a conventional canning system [88]. Coronel et al. developed a process for rapid sterilization and aseptic packaging of OFSP purees using a continuous flow microwave system operated at 915 MHz [88]. In this process, the SP puree is loaded into a hopper, and pumped through the system. Microwaves from a generator are delivered to sterilize the puree at 130–135°C, retain in the holding tube for 30 seconds, rapidly cool in a tubular heat exchanger, and then aseptically package in aluminum polyethylene laminated bags [89]. The process is short and produces at least 1 year shelf-stable product, packed in flexible polythene bags, with relatively less sensory and nutrient degradation. The process is protective of micronutrients so there is the possibility of retaining at least 85% of carotene and anthocyanins in the finished puree. **Figure 2** shows an overview of typical puree machine with aseptically packaged OFSP puree. CIP has also developed a shelf-stable, vacuum-packed OFSP puree that is increasing the supply of OFSP puree and making it available at all seasons.

This process is reportedly suitable for OFSP as well as purple-fleshed sweet potato puree processing [90] especially in the developing African countries. It has opened

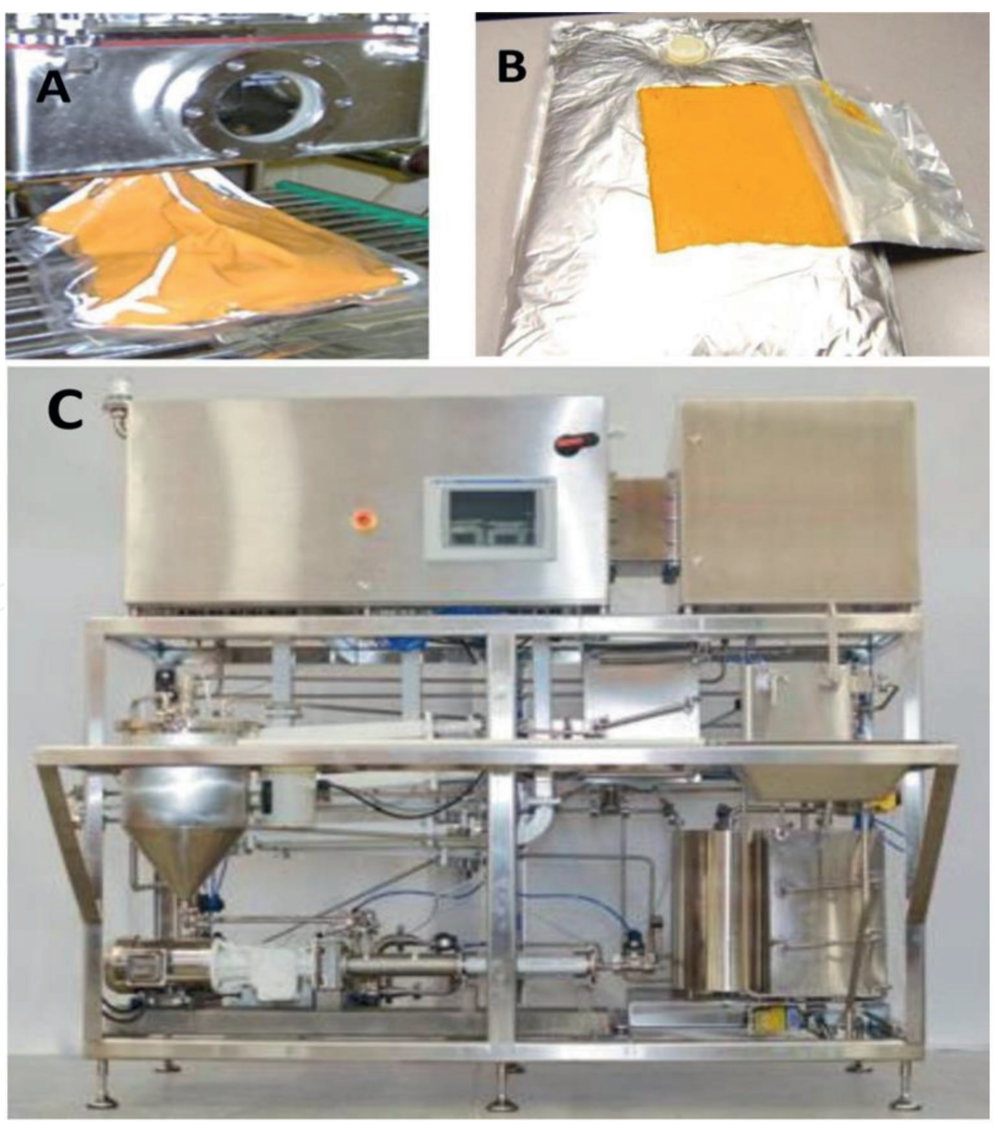

Figure 2.
A typical puree machine with the aseptically packaged OFSP puree. Source: Moyo et al. [93].

up new market opportunity for the SP industry generally and can also be applied to purees from other fruits and vegetables [91].

With the recent commercial development of the microwave-assisted processing and aseptic packaging of sweet potato purees, it is expected that more processed food products from the puree will be developed. African countries, precisely Kenya, Rwanda, Malawi, and Uganda among others, have been growing gradually in the commercialization of OFSP puree and the subsequent wheat flour substitution in bakery products. Private companies in Malawi and Kenya are now manufacturing OFSP 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. Recently, orange-fleshed sweet potato puree has replaced 20–50% of wheat flour in cookies, donuts, and breads by some commercial bakeries in Ghana, Kenya, Malawi, Rwanda, and Uganda [92]. Some processing companies in some African countries have been committed to OFSP processing and product development using OFSP puree-Tehila Bakery and Value Addition Center in Malawi; Organi Limited and Euro Ingredients Limited in Kenya; Sinagerard in Rwanda; Sanavita, SUGECO and Better Markets for Crop Products Limited (BMC) in Tanzania; Farmorganics Nigerian Limited in Nigeria. These have resulted in positive impacts on income 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. With these innovative processing technologies and successful piloting of the product, OFSP puree has been described as "breakthrough product" for Africa that offers the much-needed nutritious products, with consumer accepted organoleptic properties [93]. However, further work needs to be done in scaling up through more public awareness and education on its multiple health benefits for all, for consumption and commercialization.

4.3.3 OFSP puree in bread bakery

Bread has been an important, common exotic cereal product consumed by most individuals in Africa. Incorporating OFSP puree into bread would significantly increase the number of OFSP consumers and reduce VAD [94, 95]. According to Wanjuu et al., "OFSP puree can replace up to 50% of the wheat flour in bread, while reducing sugar (90%), 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" [96]. The composite bread has a better sensory quality (flavor, color, and soft texture), which contribute to its acceptability. Other benefits include low production costs and improved vitamin A content [97]. The OFSP puree-based bread is commercially available across sub-Saharan Africa (SSA) and is being promoted for its added nutritional benefits, which is increased β-carotene. This serves as a good medium for intake of β-carotene and to alleviate vitamin A deficiency (VAD) especially among the vulnerable populations in SSA. OFSP puree can replace some of the white, wheat flour in baked and fried products especially in the SSA where some of the countries import wheat flour at very huge costs. According to Moyo et al., 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 [93]. Substitution of wheat flour with OFSP puree up to 50% can significantly reduce dependency on imported wheat flour, enhance utilization and consumption of locally produced OFSP, create jobs for smallholder farmers, women and youths, and ultimately contribute to national economy.

OFSP puree in bread and other baked products makes puree a sustainable solution to the perishability and all-year unavailability of the crop [96]. It also encourages expanded production, utilization and consumption of OFSP-based baked products as well as meeting consumers' daily requirement of vitamin A either fully or partially. According to Wanjuu et al., (2018), bread made with OFSP puree had a longer shelf-life than the conventional white bread from 100% wheat flour, probably because of the significantly higher water activity in white bread than in the OFSP bread [96]. Using OFSP, either as flour or puree in bread making has implications on its sensory characteristics, and quality control of wheat flour-based bread [98]. OFSP pureed bread has been described by Olatunde et al. as having deeper brown colored crust, softer crumb, more uniform crumb cell, higher loaf volume (872–885 cm^3), specific volume (4.59–4.76 g/cm^3), oven spring (0.50–1.00 cm), softness (18.35–20.20 mm), crust moisture (18.05–18.17%) and consumer acceptability (7.14–7.50). In terms of consumer acceptability, bread from OFSP puree was more acceptable than that of OFSP flour [98].

4.4 VAC processing and products

Like the white varieties of cassava, yellow cassava also starts to spoil within 2 days after harvest, hence the need to process the roots into various intermediate and finished products through different processing techniques.

Yellow cassava roots can be dried in peeled, cut into chunks/sizes, or grated form for different value-added products. As much as possible, drying conditions for yellow cassava should be protective of the provitamin A (carotenoid) in it.

Similar to the white varieties, yellow cassava can be processed into traditional foods such as *gari, fufu, akpu, tapioca*, and starch; the only difference is the color of the food products, which in this case is the yellow color and it is an indication that provitamin A is present in the food. It is an added advantage over the white varieties. **Figure 3** shows various traditional products from cassava processing-*Pupuru, Garri,*

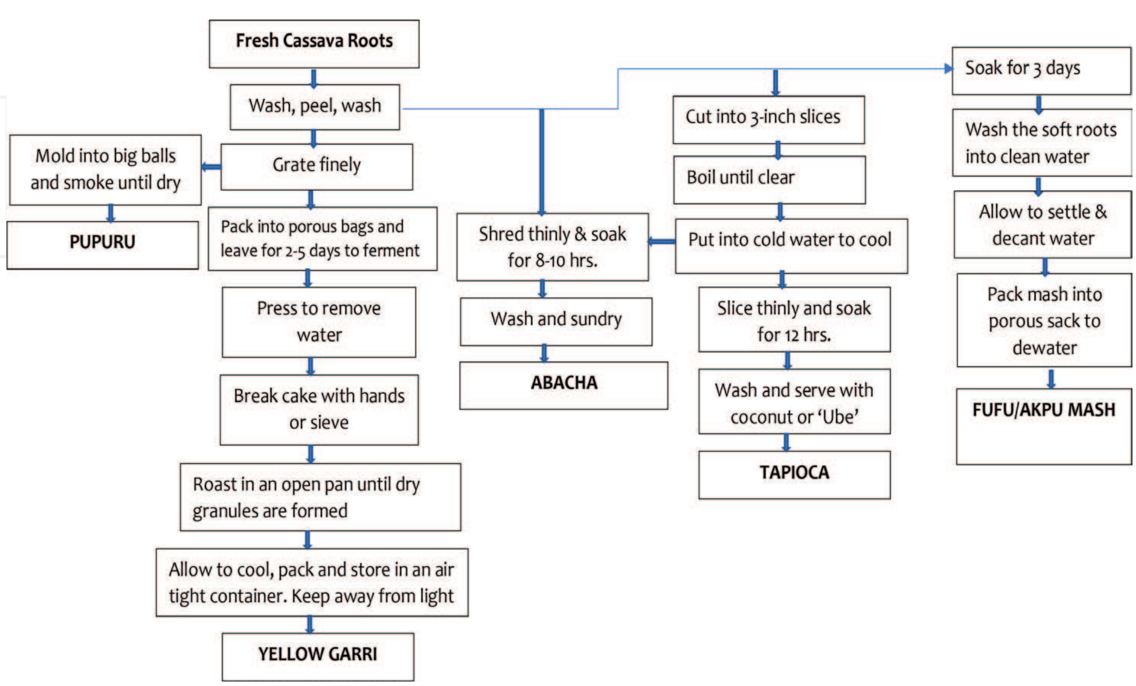

Figure 3.
Traditional VAC products. Source: Phorbee et al. [35].

Fufu/Akpu, *Abacha*, and Tapioca, which are processed through various unit operations like grating, pressing (dewatering), soaking, fermentation, roasting, etc.

Novel food products like pastries and some confectionaries have also been made with yellow cassava through high-quality cassava flour or grated and dewatered fresh roots, for both household dietary diversity and income generation/livelihood. Some Nigerian recipes have been developed for novel VAC-based foods, which use high-quality cassava flour for household consumption of carotenoid-rich foods as well as income generation at micro scale [35]. These include VAC pastries and snacks, puree, etc.

4.5 Drying technologies of cassava and VAC

Drying is a unit operation aimed at removing nearly all the free water present in a food stuff [99]. The commonly used methods of drying cassava in SSA include open sun drying on bare ground, raised platforms, road sides, roof tops, and tarpaulins as well as use of solar dryers. The selection of an appropriate drying method is necessary to ensure good quality products and prolonged shelf life.

4.5.1 Sun-drying of pressed cassava mash

Sun drying is an ancient drying technology of cassava when processing into chips, flour, or starch. Fresh cassava roots are highly perishable as they contain 65–70% moisture, and take time to sun dry. Prolonged sun drying has implications on the product quality as it is prone to spoilage and/or contamination from rain, wind, dust, insect infestation, animal attack, and microbes. Reduction of moisture is a key step in processing cassava roots into flour and must be done quickly to avoid lowering product quality. It is therefore better to remove as much water as possible by grating and pressing the cassava mash in a jack press for about 2 hours (dewatering) before drying. Sun drying is done by spreading the wet product on a clean concrete drying floor or a black plastic sheet laid on top of a concrete drying floor. The wet product needs sunlight, dry air (low humidity), and good airflow over it to dry effectively. Sun drying, therefore, depends on availability of sunlight and so it is challenging during raining season, which limits availability of cassava flour or starch all year round. Also, it is best suited for small-scale rural operations where product volumes are low (50–100 kg of dry product per day) [100]. Furthermore, sun drying exposes cassava to sunlight and so not suitable for biofortified cassava varieties.

Just like white cassava varieties, yellow cassava varieties have been reported to be relatively high in moisture content and so prone to deteriorations after harvest [101], thus necessitate post-harvest processing. However, yellow cassava being biofortified with carotenoid (pro-vitamin A), is thermal and photo sensitive so exposure to sunlight during drying can lead to significant loss of the carotenoid and therefore defeat the purpose of its biofortification.

To preserve the carotenoid content and also process yellow cassava roots into chip or flour all year round, alternative drying technologies that are protective of the biofortified vitamins in the cassava roots have been exploited over time. These include cabinet/tray dryer, drum dryer, solar dryer, and flash dryer.

4.5.2 Flash drying technology

The flash drying technology is a high-precision indoor novel drying technology that involves instant drying of a wet material by passing hot air through it, to quickly evaporate free moisture in the material, using rapid heat transfer. Flash drying is an efficient and effective drying technology as the process facilitates fast evaporation through speedy heat transfer. The technology can be applied to food, feed, and some other industrial materials. The drying process, being rapid makes it a suitable technology for nutrient-dense foods as the short exposure to heat favors retention of nutrients especially the thermally sensitive micronutrients.

4.5.2.1 Principle of flash drying

The principle of flash drying is instant evaporation of free surface moisture from a wet material mixed with hot air. Wet particle material is passed through hot air or steam where the particles are dried almost immediately and the gas or steam temperature decreases due to heat transfer [102]. The wet material, either in paste or cake is pulverized into fines and increase the surface area, to hasten the drying process. The dried material (usually in powder form) remains suspended in air and conveyed while drying [103]. Being a short-time dryer, it is very suitable for biofortified provitamin A cassava as it protects the beta carotene in the cassava unlike sun drying with a prolonged exposure to sunlight. According to Kuye et al., the output of flash drying technology is significantly improved compared to those of general drum or cabinet drying. Through it, users can achieve higher economic benefits in the short term.

4.5.3 Flash drying technology for VAC

For cassava, flash drying technology came at an opportune time, using flash dryer, which was fabricated and introduced in Nigeria by CAVA-Cassava: Adding Value in Africa project in 2016 [28]. Flash drying is achieved with flash dryer, a high-tech equipment, designed to dry pressed (dewatered) cassava mash into High Quality Cassava Flour (HQCF) within seconds, and can process 3–7 tons of HQCF per day. Flash dryers have been reported suitable for drying mash and solids of moisture content between 30 and 40% and applicable not just in food industry but also other industries like feed, chemical, and pharmaceutical [28]. A flash dryer is generally constructed with devices, which can simultaneously dry, pulverize and classify materials by particle sizes. It is a continuous drying device specially designed for drying cake, paste and muddy materials. A flash dryer must be able to resist the intense heat and rapid movement required in the drying process, so it must typically be fabricated with strong, detailed construction materials and accurate temperature control device. While other features of the dryer are specific to intended use, it is usually customized for purpose. Flash dryers, although expensive in fabrication, is low in energy consumption, high in thermal efficiency, occupies small area thus saving factory space and efficient in continuous mass production.

Specifically for drying cassava and VAC, the flash dryer by feature, typically consists of a blower, air pre-heater, feeding mechanism, (hopper, pulverizer, screw conveyor, and a rotary air lock), dryer, cyclone, and filter as shown in **Figure 4**. Wet-pressed (dewater) cassava to be dried is loaded into the feed mechanism while the air, after passing through an air filter, is heated in a hot air generator (steam can also be used). The wet cassava mash is circulated into the hot-air for thorough mixing. The pulverized cassava mash and the hot air mixture is conveyed through the dryer to the cyclone using pressure from the blower. The cassava mash gets dried through quick moisture loss and the moisture absorbed by the hot air, thus lowering the air temperature (and increasing the humidity). The mixed air and dried cassava flour

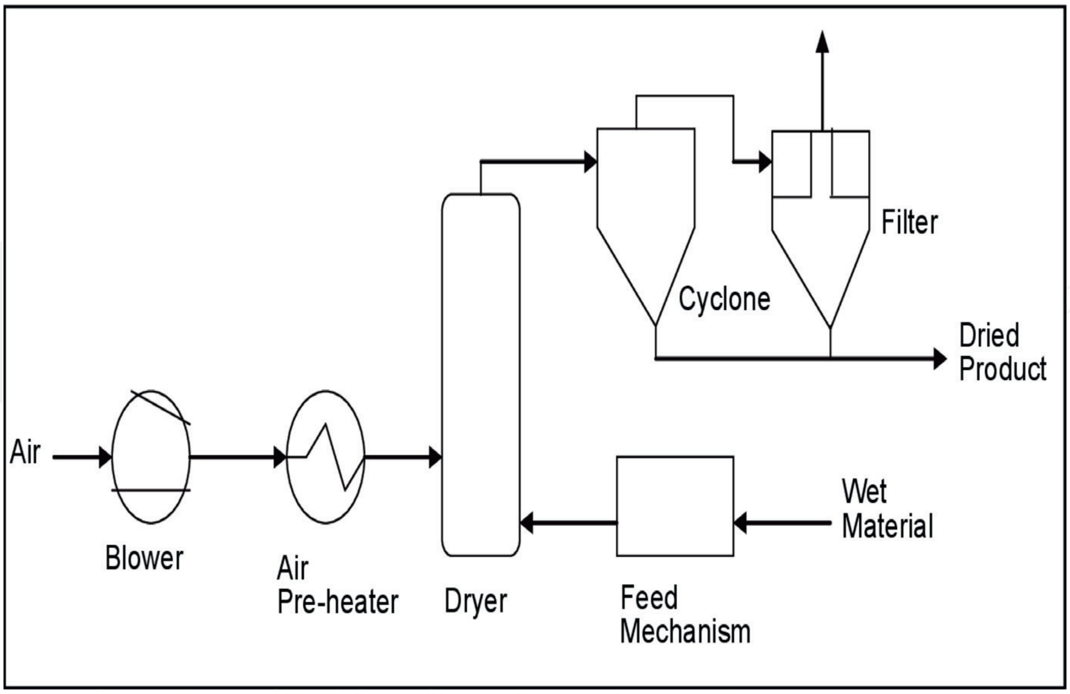

Figure 4.
Schematic diagram of a Flash Dryer: Source: Kuye et al. [103].

are separated in the cyclone, and the flour is let out from the cyclone through the discharge valves. Fine cassava flour particles that escape from the cyclone are trapped by a bag filter. Kuye et al., gave the specification of all the devices of a typical cassava flash dryer [103].

This flash dryer is not only for making high quality cassava flour, but can also be used to dry cassava starch and *fufu* cake for dried cassava starch and instant *fufu* flour, respectively. VAC can also be used to make *fufu* mash and instant *fufu* flour, which are cooked at home as a meal ("swallow") and consumed with any choice of soup in West Africa. Use of flash dryer is very suitable for VAC as it is a rapid drying process, which favors retention of the pro-vitamin A in the biofortified cassava. With flash-dried cassava flour and *fufu* from VAC, consumers' access to vitamin A is guaranteed because of high retention of the vitamin after processing. Consumption of instant *fufu* flour is growing in Nigeria and Ghana due to increased urbanization and reliance on instant convenient foods. This presents a good opportunity for the consumers to be reached with VAC *fufu,* dried with flash dryer that retains the beta carotene in the biofortified cassava and contributes to the fight against vitamin A deficiency in the consuming countries of SSA. However, increased consumers' acceptance and access to these products is still necessary.

5. Conclusion

With the advances made so far, on appropriate post-harvest technologies, processed biofortified crops have potentials to improve food and nutrition security in the sub-Saharan Africa, if fully exploited. Processing the biofortified crops into products improve availability, reduce post-harvest losses significantly, and create more options for consumption and commercialization, as the crops can be processed in various ways, using various techniques of cooking and drying. With these available technologies, the shift from non-biofortified to biofortified food consumption is a significant move towards improved food system transformation. OFSP puree with the SSA-friendly technology of aseptic packaging and continuous flow microwave system of rapid sterilization ensures a stable supply of high-quality shelf-stable nutritious product, with minimal carotenoid degradation to consumers. The technologies are indeed breakthrough within the biofortification sector in the SSA, leveraging on the versatility of the crops especially OFSP, which contains some functional components. OFSP puree is an important intermediate product with existing and potentials for diverse finished products in the food industry especially confectionaries and beverages. Similarly, biofortified cassava processing into flour, starch, and instant *fufu* flour using the flash drying technology of rapid evaporation through heat transfer, produces high-quality products that ensure delivery of pro-vitamin A to consumers. With cassava being a key staple in many SSA countries, consumer shift from white to yellow cassava will be a major revolution in household reach with vitamin A especially the rural consumers who are easily left out of the micronutrient interventions.

The shelf stability of the products from these advanced technologies also favors sustainability of consumers' access to nutritious crops thus realizing the purpose of biofortification, which is to contribute to the fight against vitamin A deficiency. In response to food insecurity and poor livelihood, the available technologies for enhanced biofortified nutritious food product development, present opportunities to significantly contribute to improved food system through enhanced utilization and consumption of locally produced crops, create jobs for smallholder farmers, women and youths, and ultimately contribute to national economy. OFSP puree makes consumer-acceptable bread, which compares very well with 100% wheat flour bread organoleptically, with increased micronutrients and functional components, reduced production cost from reduced use of wheat flour and sugar.

However, there is need for continued research on biofortified crop cultivar screening targeting more diverse end uses, with technology transferred to the end users through private-public engagement. This way, interest of the key actors of the value chain (Breeders, Farmers, Processors, and Marketers) will be stimulated towards biofortified crops. This is an awareness/adoption strategy, which should also be scaled up with favorable polices.

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Conflict of interest

The authors declare no conflict of interest.

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