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African Fermented Foods Are Valuable In Achieving Good Health In Sub-Saharan African

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Abstract

Background:Sustainable development goals (SDGs) have become global goal with various levels of commitments and efforts from different countries. To achieve certain SDGs, such as zero hunger (SDG2) and good health (SDG3) it is essential to give attention to Sub-Saharan Africa (SSA). Fermented foods make up a large proportion of African diets, however, many have not received scientific attention or commitment.**Aim**:The aim of this review is to highlight some of these traditional fermented foods and their potential benefits in achieving good health target of the sustainable development goal. **Discussion**:Food insecurity is a global crisis; however, it has a heavier weight in some regions of the world, such as the SSA. Food fermentation may be essential for sustainable development because it helps in achieving food security through food preservation. These cultured foods make raw materials more digestible, nutritious, accepted by consumers because of new flavours. Africa is home to varieties of fermented foods, and many have not receive scientific attention. The scarcely reported fermented food of African origin includes cereal-based (*degue, koko*), legume-based (*tayohounta, ntsambu, cachupu*), vegetable-based (*kawal, ntoba mbodi, kocho*), milk-based (*urubu, mursik, kivuguto*), and fruit-based (*akwandu, dockounou*) foods. Cassava flour/dough, maize-based *ogi* and legume-based *iru* are relatively research and considered low hanging fruits to achieve sustainability. Despite the potentials of fermented foods in contributing to good health in Africa barriers such as how to increase quality substrate yield, safe and hygienic production, food safety, commercialization, and trade still hamper these products.**Conclusion**:A comprehensive understanding of the microbiota and microbiome of these fermented foods is crucial in enabling their full health benefits and addressing their risks and implications.

Keywords: Fermented Food; African Food; SDGs; Sustainability; Poverty; Hunger; Nutrition; Development

Introduction

Today, there is a universal call to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030. These goals are Sustainable Development Goals. According to Costanza *et al.* (2016), one hundred and ninety-three countries agreed to support the 17 SDGs as a collaborative effort towards sustainability. The goals seek to guide the world in its sustainable economic development. In addition, SDGs emphasize tackling malnutrition and improving good health around the world (UN, 2016).

Africa is central to tackling SDG 1 (no poverty), SDG 2 (zero hunger) and SDG 3 (good health and wellbeing) since poverty, hunger and weak health systems and programmes reside mainly there, particularly in its Sub-Saharan region (Fagunwa and Olanbiwoninu, 2020). Africa is off-track and experiencing a rapid rise in poverty. Ending hunger and every form of malnutrition is an immense challenge, especially when the forecasted population growth for the year 2050 in Africa is about 50% while Europe and North America will only experience a 2% growth rate (UN DESA, 2019). The production of enough safe food is at the heart of food security and safety. Attaining good health and wellbeing is adversely impacted by cofactors such as extreme poverty and food insecurity. Such food insecurity is the experience of millions of people in SSA. The understanding of potential home-grown solutions may be a sustainable way forward.

Kuhad (2012) suggests that reasonable use of microorganisms can be instrumental for sustainable development. There is a recent review on how microbes can help achieve each SDGs (Akinsemolu, 2018; Fagunwa and Olanbiwoninu, 2020). Microorganisms play a crucial role in food fermentation. Evidence demonstrates that man consumed fermented foods in Babylon about 7000 years ago (Egwim-Evans, Abubakar and Mainuna, 2013). Fermentation helps achieve food security through food preservation, makes food more digestible and flavoured, and adds nutritional value. In addition, food fermentation and the SDGs have a unique relationship that can enable the former to contribute to the continent's socio-economic development positively. Fermented products can play a crucial role in income generation, thereby helping to end poverty. At the same time, they provide beneficial gut microbes and probiotics when produced and consumed safely.

Fermented foods make up a large proportion of African diets and are usually classified into various categories based on the substrate used to make them. Of the categories, root-based, cereal-based, and vegetable-based fermented products stand out because they are the most consumed by the population (Odunfa and Oyewole, 1998; FAO, 2018). Within these three classes, cassava, maize, and legume are mainly used for fermentation. However, some of them are yet to be explored scientifically or for their potentials to support achieving the SDGs (Table 1 and 2). A comprehensive understanding of the microbes present in fermented foods can be crucial in enabling their benefits and addressing their implications, such as food safety. More importantly, Africa has abundant fermented foods, which can contribute to achieving some of the SDGs. For instance, the locals consume fermented foods because of their claimed health benefits (Table 1). However, there are increasing safety concerns with many of these products, but these concerns can be overcome if the products receive needed attention in the scientific community, industry, and government. This review focuses on fermented foods commonly used in different countries in Africa and their potential to foster the SDGs. Emphasis is on Sub-Saharan Africa as these countries have shared culture, food, and challenges compared to Arab African countries.

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Table 1: Some traditional fermented food and their historical usage or health benefit in SSA

Name	Country and Region [a]	Historical Benefits	References
Amahewu	South Africa	Weaning and management of gastrointestinal problems. Detoxification of toxins associated with maize	Simango 1998; Chelule *et al.* 2010
Ogi	Nigeria	Management of gastrointestinal disturbances, sickness convalescence, lactation adjuvant, weaning food for infants; Hypolipidemic property	Olukoya *et al.,* 1994; Kwasi *et al.*2005; Aderiye *et al.,* 2007;
Bikalga	Burkina Faso	Cure for eye infections and intestinal problems.	Ouoba *et al.,* 2008.
Borde and Shamita	Southern Ethiopia	Meal supplements/replacements Enhancement of lactation	Ashenafi and Mehari, 1995; Nemo and Bacha, 2020
Datou	Mali	Condiment for flavouring of stew and soup	Sarkar and Nout, 2014
Dawadawa botso	Niger	Condiment for flavouring of stew and soup	Ibrahim *et al.*, 2018
Kenkey	Ghana	Weaning and management of stomach pain	Annan-Prah and Agyeman, 1997
Lanhouin	Benin	Condiment for flavouring of stew and soup	Anukam and Reid, 2009
Mawe	Benin and Togo	Pro-convalescent after illness	Hounhouigan *et al.,* 1993; Steinkraus, 2018
Mbege	Tanzania	Relieve of constipation and bowel disturbances	Kubo, 2016
Mursik	Kenya	Enhancement of mother and fetus health during pregnancy	Riang'a *et al.,* 2017

Nunu	Northern West Africa	Improvement of the immune system	Obi and Ikenebomeh, 2007
Uji wa wimbi	Kenya	Management of gastrointestinal disturbances	Anukam and Reid, 2009

[a] This is country of production and with high consumption. **Bold** – have scientifically proven benefits

A literature search was done in the English language, and only references available in English were reported. Furthermore, one common fermented food per African country with reports of health benefit is included.

Table 2: Important but scarcely research/reported traditional fermented food products in SSA

Name [a]	**Main Countries** [b]	**Types of Fermented Food**	**Substrate**	**Description**	**Microbial community**	**References**
Funge	Angola	Cereal	Corn/Maize, Cassava	Angolan national staple food. Corn type is popular in the south and cassava type in the north. Angolans often eat it on all menu.	Not Available	Lancaster *et al* 1982; Stead and Rorison, 2010
Baobab Tayohounta	Benin	Legume/Seed	Baobab	Baobab is a common condiment among Otamari (or Somba) ethnic group. It is made after two days of fermentation of baobab kernel, yielding pH 7. Usually, sun-dried to increase shelf life and reduce spoilage.	Mesophilic aerobic bacteria, Spore formers (perhaps Bacillus sp.), Lactic Acid Bacteria	Chadare *et al.*, 2010
Degue	Burkina Faso, Benin	Cereal	Pearl Millet	Starchy fermented gruel. Accompanied with sugar, milk, honey and citron juice. pH 4.5, 3 days fermentation. Similar to fura in Nigeria	Lactic Acid Bacteria – Lactobacillus, Enterococcus, Pediococcus, Weisella, Streptococcus, Yeasts,	Savadogo *et al.*, 2009; Angelov *et al.*, 2017

					moulds,	
Urubu	Burundi	Milk	Bovine milk	Thick and smooth sour milk that naturally ferment between 1-3 days. Low acidic pH. By-products include Amavuta (butter) and Amateregwa (buttermilk). It is similar to Ergo in Ethiopia	Not Available	Nzigamasabo and Nimpagaritse, 2009
Cachupu	Cape Verde	Legume/Seed	Mixed beans - Lima, green	Corn/maize-based dish with dried beans, vegetables and meat or fish. The national menu is now replaced with rice. The average consumption among Cape Verdeans is five times per month.	Not Available	Craveiro *et al.,* 2016; Cabral *et al.,* 2019
Kawal	Chad, South Sudan	Vegetables	*Cassia obtusifolia* leaves	Kawal is a meat replacer or meat extender. It takes 15 days fermentation time, producing repugnant, putrid-smelling black paste, which can then be dried. It is claimed to help in the management of jaundice, stomach aches and fatigues	*B. subtilis,* Rhizopus	Dirar, 1984; Mbaiguinam *et al.,* 2005

Ntsambu	Comoros	Legume/Seed	fruit seeds of cycad	Seeds are wrapped in banana leaves, buried in soil, and fermented for 5-14 days or until rotten. Then washed and boiled in water for 2 hours to remove odour. Foul-smelling product is prepared in a coconut sauce garnished with fish. Odourless form exists in flour form in Zanzibar, Tanzania.	Not Available	Walker, 2012
Ntoba Mbodi (Kingouari)	Republic of Congo, DRC	Vegetables	Cassava leaves	2-4 days alkaline fermentation resulting in pH 8.6. Enzyme activity includes pectate lyases, polygalacturonase, pectinesterase, cellulases. High nutritional value.	*A. calcoaceticus*, *A. radiobacter*, *Erwinia* sp., *Lysinibacillus, Micrococcus*, Pediococcus, Weissella, and various species of Bacillus, Lactobacillus and Enterococcus	Kayath *et al.,* 2016
Pilipili	Republic of Congo, DRC	Vegetables	Chilli (Capsicum sp)	Fermented hot chilli sauce, garnished with oil onions and other vegetables	Not Available	Kayath *et al.,* 2016; Kittler *et al.,* 2017
Dockounou	Cote D'Ivoire	Fruits	Plaintain	Dockounou is fermented over riped plantain fruit. It is sometimes supplemented with rice or maize flour. Mixture with rice flour yield more CFU of fermenting microbes after 4 hour	*Bacillus* sp., Lactic Acid Bacteria, yeast	Akoa *et al.,* 2013; Kouadio *et al.,* 2014

Akwandu	Equatorial Guinea	Fruits	Banana	National breakfast and also serves as a dessert with sprinkled coconut flakes. It is often barbequed	Not Available	www.196flavors.com
Emasi	Eswatini (Swaziland)	Milk	Milk	Spontaneously fermented milk. It takes about 2-3 days fermentation time, and it is similar to cottage cheese	Possibly Lactic Acid Bacteria	Gadaga *et al*., 2015
Injera	Ethiopia, Somalia	Cereal	Rice or Eragrostis tef	Pancake-like yeast-risen flatbread. Involve 2-3 days fermentation based on backslopping - "ersho". The pH is 4. **Reduces anti-nutritive phytic acid, which may cause mineral deficiency.**	Lactic Acid Bacteria (*L. plantarum, L. fermentum*), Yeasts (*S. cerevisiae, P. fermentans, P. occidentalis, C. humilis, K. bulderi.)*	Fischer *et al.,* 2014; Shumoy *et al.,* 2017; Hassen *et al.,* 2018; Tadesse *et al.,* 2019
Kocho	Ethiopia	Vegetables	Enset plant (Ethiopian Banana) with its trunk pulp used as the starter culture	It is made from a mixture of the scraped pulp of pseudostem and pulverised corm of enset plant. Used traditional starter culture (gamancho) ferment for 8 -10 days. The enset has two fermentation stages (surface -15 days and pit -15days) pH 4-4.5	Lactic Acid Bacteria, yeasts, mesophiles, Enterobacteriaceae	Karssa *et al.,* 2014

Koko	Ghana, Nigeria	Cereal	Pearl millet	It is a cheap weaning porridge with some antibacterial effect on *Salmonella typhi*, *Vibro cholerae*, *Shigella flexneri*, *E. coli*. The ingredient includes cloves, ginger, black pepper. 2-3hours fermentation, pH 3.5-4.0. By product, koko sour water is tolerant to bile and acid and has a gastrointestinal benefit because of Lactobacillus and Pediococcus content.	Lactic Acid Bacteria, *W. confusa, L. fermentum, L. salivarius,* Pediococcus,	Bakare *et al.,* 1998; Lei and Jakobsen, 2004
Mursik	Kenya	Milk	Milk	It is like yoghurt and kefir, but with a sharp sour taste due to charcoal powder from a herb. It can be consumed with ugali. It has a pH of 3.5 after 14 days of fermentation.	Yeast - (*C. krusei, C. kefyr, C. sphaerica, S. fermentii*) LAB - (*L. kefiri, L. casei, L. paracasei, L. rhamnosus*). Bacillus sp.	Nieminen *et al.,* 2013; Kirui and Nguka, 2017
Motoho	Lesotho	Cereal	Sorghum	Slurry-like sour porridge. 1-day fermentation but could take up to 3 days during winter.	Lactic Acid Bacteria, yeast,	Gadaga *et al.,* 2013; Moodley *et al.,* 2015
Poi	Madagascar	Root and tuber	Taro (Cocoyam)	The substrate is one of the oldest food, originating from Asia and now with global diversity. pH 3.5-4.0	Lactobacilli, yeast	Ramanatha *et al.,* 2010
Thobwa Also called *Togwa*	Malawi, Tanzania, Zambia	Cereal	Maize and millet, sorghum	Milky appearance drink in a grainy texture. The pH is 4.5, and it ferments for 18 hours. Mixing thobwa with fermented soya	Lactic Acid Bacteria	Ngongola-Manani *et al.,* 2014; Hjortmo *et al.,* 2008

				beans products give a better diet.		
Oshikundu	Namibia	Cereal	Pearl Millet and Sorghum	It is a mixture of millet and sorghum, which contains vitamins and minerals. It ferments for 4-6 hours by backslopping. It has a bitter taste	Lactic Acid Bacteria –*L. plantarum, L. lactis, L. delbrueckii, L. fermentum, L. curvatus and L. pentosus*	Embashu *et al.,* 2012; Misihairabgwi and Cheikhyoussef, 2017
Abacha	Nigeria	Root and tuber	Cassava	Shredded or grated cassava ferments for 8-24 hours, usually consumed by people in eastern Nigeria as a snack. It also serves as a salad. It has a pH of 5.7. **The Lactic Acid Bacteria in abacha reduces the anti-nutritive factors of sorghum.**	Lactic Acid Bacteria – *L. casei, L. plantarum, L. cellobiosus, L. fermentum, L. acidophilus, L. brevis*. Aspergillus, *Bacillus* sp., *Saccharomyces* sp., *Candida* sp., *Staphylococcus aureus*	Adeyemo *et al.,* 2016; Ihenetu *et al,* 2017; Davidson *et al.,* 2017
Kivuguto (Ikivuguto)	Rwanda	Milk	Cow milk	Made from coagulated raw cow milk and share similarity with other fermented dairy products in Africa. Shelf life can be up to 35 days.	*Lc. lactis, Leuconostoc mesenteroides, Leuconostoc pseudomesenteroides* (including a pH, NaCl and heat resilient *Leuconostoc* sp.)	Karenzi et al., 2012; Karenzi *et al.,* 2013

Guedj	Senegal	Fish	Fish – *Arius latisculatus, Pseudotolithus brachygnatus*, *Pomadasys jubelini*	Brown fermented fish and characterised by a strong, pungent smell. It is used as a seasoning in food and a source of animal protein. Fermentation for 1-3 days, yielding pH 6.4 and contain a large amount of salt (30-40%) for a longer shelf-life. Some LAB bacteria isolated displayed antagonistic activity against *E. coli* and *L. monocytogenes*	Lactic Acid Bacteria – *L. plantarum, L. brevis, L. curvatus, L. fermentum*, Lactococcus (*Lc. lactis* sp. *Lactis*), Enterococcus (*E. feacium*), Leuconostocs (*L. mesenteroides*), *P. pentasaceus*	Fall *et al.*, 2017; Fall *et al.*, 2018;
Gariss	Sudan, South Sudan	Milk	Camel milk	Traditional fermented camel milk	*L. plantarum, L. pentosus*, Enterococcus (*E. hirae, E. faecium, E. durans, E. dispar, E. fecalis, E. sanguinicola, E. mundtii*), Streptococcus (*S. thermophilus, S. acidominimus*)	Ahmed *et al.*, 2012
Munkoyo	Zambia, DRC	Root and tuber, Cereal	Maize-based with different roots mixture (Rhychosia, Eminia, Vigna)	Non- alcoholic herbified beverage, popularly known as 'sweet beer' among Zambians. 1-2 days fermentation yielding sweet-sour taste at pH3.5	*L. plantarum, W. confusa, Lc. lactis, E. italicus*, Leuconostocaceae, Acetobacter, Gluconobacter, Acinetobacter, Chryseobacterium	Zulu *et al.*, 1997; Schoustra *et al.*, 2013; Phiri *et al.*, 2019

[a] A literature search was done on google, google scholar and dimensions AI, material written in English language and those fermented foods that are least known were selected. Where possible, the selection was made for each SSA country and their representative least reported fermented food.

[b] This is country of production and with high consumption. **Bold** – scientifically proven

There is a new nomenclature for '*Lactobacillus*' by Zheng *et al.,* (2020), and it is used throughout this manuscript

Acinetobacter – A. calcoaceticus Agrobacterium – A. radiobacter Bacillus – B.subtilis Candida – C. humilis, C. krusei C. kefyr, C. sphaerica Enterococcus – E. hirae, E. faecium, E. durans, E. dispar, E. fecalis, E. sanguinicola, E. mundtii, E. italicus, Kazachstania – K. bulderi Lacticaseibacillus – L. rhamnosus, L. paracasei, L. casei Latilactobacillus – L. curvatus Lactiplantibacillus – L. pentosus, L. plantarum Lactobacillus – L. acidophilus, L. delbrueckii Lactococcus – Lc.lactis Lentilactobacillus – L. kefiri Leuconostoc – L. mesenteroides Levilactobacillus – L. brevis Ligilactobacillus – L. salivarius Limosilactobacillus – L. cellobiosus, L. fermentum Pediococcus – P. pentasaceus Pichia – P. fermentans, P. occidentalis Streptococcus – S. thermophilus, S. acidominimus Weisella – W. confusa

SSA fermented foods and SDGs consideration

Fermented foods constitute a large proportion of the African diet. One of the importance of food fermentation in Africa lies in providing improved flavours to existing staples such as cereals and root crops. It is also a cheap way to preserve food and enhance natural products' nutritional quality and digestibility (Olasupo *et al.,* 2010). As highlighted in table 1, African fermented foods have both claimed and scientifically proven to provide health benefits (Table 1). There are numerous alcoholic beverages of African origin, such as palm wine, pineapple wine, burukutu. However, this work focuses on non-alcoholic beverages since they are widely acceptable and compatible with cultural and religious values in Africa. More so, it will be easier to scale up production after optimization and gain wide acceptance by the millions of people who need them for essential means - zero hunger and good health. To discuss the connection between fermented food and SDGs, discussion will be on specific crops and their linkage with SDGs, especially good health and wellbeing. Of the crops used in fermentation in Sub-Saharan Africa, cassava, maize, and legume appear to have gained considerable research efforts and will be helpful for sustainability consideration.

Cassava-based (Root)

Cassava (*Manihot esculenta* Crantz) is a root crop with the most abundant starch food in the tropics. Over 61% of the world cassava production comes from small farms in Sub Saharan Africa (Spencer and Ezedinma, 2017). Humans consume most of the cassava produced in Africa as fermented products. Everyday fermented cassava products include *gari, fufu, lafun* or *kokonte, agbelima, attieke, kumkum, myiodo, atangana, placali, makaka, maphumu* (Odunfa and Oyewole, 1998).

Cassava is a poverty fighter and contributes to farmers income. A study found that cassava farmers can earn $67 - 134 daily. Such income help in taking care of basics needs such as purchase of clothing material, payment of school fees and cost of health care services, thus helping to reduce the rate of poverty among the populace of developing countries (Fakoya *et al.*, 2010). However, for cassava to become an established income-earning crop among small farmers, obstacles with post-harvesting processing and regional trade barriers must be removed (Ye, 2012). In addition, cassava-based fermented products can be a vehicle for tackling health issues. The biofortification of cassava has significant potential for continuing impacts in correcting critical essential vitamins and minerals deficiencies. For instance, governments can use biofortified cassava to tackle Vitamin A deficiency (VAD), a prevailing public health challenge in many Sub-Saharan countries. While several interventions have attempted to reduce this burden, few have promised sustainable impact on a large scale compared with the biofortification of crops (Lockyer *et al.,* 2018; Eyinla *et al.,* 2019). Thus cassava, which is a chief source of dietary carbohydrate in local diets, when biofortified with increased carotenoids, can offer other nutritional benefits, such as contributing to improved functioning of visual and immune systems (Krinsky and Johnson, 2005). Cassava safety concern lies in the mode of processing and variety been consumed. Partial fermentation, through soaking, eliminates cyanogens and cyanide poisoning (Nweke, n.d; Alitubeera *et al.,* 2019). Cassava is broadly classified into bitter and sweet varieties. The bitter varieties are common in Congo, Nigeria, and Tanzania. The sweet varieties common in Cote d'Ivoire, Ghana and Uganda, are usually cooked and consumed without soaking and sun-drying. For example, the 2017 Ugandan outbreak of suspected cyanide poisoning, involving 98 cases, was caused by the consumption of cassava flour dish made from highly cyanogenic content (Alitubeera *et al.,* 2019). Hence, low cyanogenic varieties of cassava are significant.

There have been cassava varieties with high pro-vitamin A content in Nigeria, where a strong breeding effort exists since 2011 (IITA, 2017; Lockyer *et al.,* 2018; Eyinla *et al.,* 2019). These varieties, also popularly referred to as "yellow cassava", are promoted in various communities (HarvestPlus, 2020). The successes have diffused into neighbouring countries within SSA, releasing similar varieties to combat VAD in burdened populations.

The microbiota present in fermented cassava includes *Firmicutes* (*Bacillaceae*, *Clostridaceae, Lactobacillaceae, Veillonellaceae*), *Actinobacteria* (*Propionibacteriaceae*), *Proteobacteria* (*Enterobacteriaceae, Vibrionaceae,*), *Bacteroidetes* (*Bacteroidales*) (Miambi *et al.,* 2003; Kodama *et al.,* 2014). The diversity of microbiota present in fermented cassava depends on the duration of the fermentation (Kodama *et al.,* 2014). Four-day fermentation gave the maximum yield of probiotics such as *Propionibacteria* and *Bacteroides* (Kodama *et al.,* 2014). Beneficial Lactic Acid Bacteria such as *L. plantarum*, *L. pentosus*, *L. fermentum*, *L. crispatus*, *L. delcrueckii* have been isolated from a fermented dough of bitter cassava (Miambi *et al.,* 2003). Specifically, *L. plantarum* exhibited better performance as a starter culture in cassava fermentation (Kimaryo *et al.,* 2000; Penido *et al.,* 2018).

Cassava bagasse, a by-product from cassava flour and starch production, was found to have prebiotic effects stimulating Bifidobacteria and Roseburia, thus producing Short-Chain Fatty Acids (SCFA) (Bussolo de Souza *et al.,* 2014). SCFA play an essential role in host health, helping to recover energy from undigested foods, supporting the integrity of the gut lining and barrier, reduce cardiovascular risk, and positive regulation of neuro-immunoendocrine functions (Chambers *et al.,* 2018; Silva *et al.,* 2020).

Aside from achieving good health and wellbeing through the naturally occurring probiotics and vitamin biofortification, cassava may be an essential element for scaling up biogas production from household level to farm/industrial level, fulfilling SDGs 1 (no poverty), 7 (clean energy) and 12 (responsible consumption and production). Cassava residues from cassava starch processing, organic waste from agro-based industries, and agricultural residues such as sawdust and rice husk can make feedstock (FAO, 2018). The temperature in Sub-Saharan Africa will support biogas production. Cassava can promote no poverty, zero hunger, good health, and affordable clean energy.

Maize-based (Cereal)

In Africa, most fermented cereal-based meals use maize, others being sorghum and millet (Odunfa and Oyewole, 1998; Adebo *et al.,* 2018). Weaning food and breakfast food for adults are usually maize-based. Because of these fermented foods' popularity, enrichment with essential vitamins will go a long way to ensure healthy living and promote wellbeing. Folate fortified *ogi* contain crucial vitamins needed during the early pregnancy stages when an embryo is rapidly growing and prevents neural tube defects. Fortification of food with folic acid showed positive results in South Africa in 2008. The South African Medical Research Council observed a 33% decline in the incidence of neural tube defects due to the increased availability and consumption of adequately fortified folic acid in fermented maize cereal (Okoroafor *et al.,* 2019). Likewise, Hjortmo *et al.* demonstrated that folate level is increased by 700% during fermentation with yeasts originally isolated from togwa (Hjortmo *et al.,* 2008). Togwa is a Tanzanian fermented maize-based porridge consumed in rural areas in Tanzania.

In Africa, Zambia and Nigeria lead in the maize biofortification research by incorporating pro-vitamin (Bouis *et al.,* 2013). A study by Kwasi *et al.* (2019) found that ogi should not be consumed beyond ten days after milling using modified ogi supernatant *(omidun*). The LAB viability in ogi reduces with day, and no LAB was present after ten days. They suggest a ten-day shelf life for Ogi. However, this shelf life is unknown to the local producer or the consumers. Hence there is a need to communicate the science to the local producers. It is usual among consumers to purchase many ogi and store them at home beyond two weeks, especially when stored in the fridge.

Science communication to the local producers is essential. Consumers should be guided by those with scientific knowledge about shelf life. The regular consumption of ogi could help towards antibiotic stewardship. Diarrhoeagenic *E. coli* were resistant to antibiotics due to indiscriminate use (Nguyen *et al.,* 2005). Interestingly, Kwesi *et al.* suggest that LAB present in ogi confer anti-diarrhoeagenic property and prevent colitis in the rat model. The ogi supernatant - omidun, also have anti-diarrhoeagenic effects, perhaps through the bioactive substances secreted by the microbes present in ogi. It will be suggestive to consider leveraging fermented foods to combat antibiotic resistance and encourage stewardship. Probiotics naturally present in abundant maize-based gruels from Africa can be optimised for their health benefits as well as used to complement efforts on antibiotics stewardship. Local/national food regulatory agencies can investigate and remedy the safety issues associated with the fermentation of maize-based gruel without depriving the locals of their source of income and livelihood. Food actors may enhance these products to give the quality that will allow for high commercialization locally or trans-continentally. For instance, if the shelf life, sensory and organoleptic, and probiotic properties of maize-based fermented food is well enhanced, it can gain an appearance in the global food market and yield substantial income for the producers and country of production. The utilization of various African fermented foods that falls into this category will go a long way to address SDGs 2 and 3.

Legume-based (Vegetables)

The most common legume-based fermented product in Sub-Saharan Africa is from African locust beans (*Parkia biglobosa*). *P. biglobosa* cotyledon is fermented in most West African belt countries to produce soup condiments, such as *'iru'*, *or 'dawadawa', 'afintin', 'soumbala', 'kinda'*, or *'netetu'*, depending on the ethnic group. The usage of this condiment cut across all levels or classes of people. However, in the quest for plant protein and vitamin substitutes, the African locust bean (*P. biglobosa*) has gained popularity, especially in its fermented form ('iru'). *'Iru'* is rich in fat and protein and contributes significantly to energy, protein and vitamin intake, especially riboflavin (Achi, 2005). Riboflavin is one of the essential micronutrients that all human requires. Its deficiency is associated with impaired vision, reduced growth rate, increased homocysteine levels with consequent cardiac risk, re-eclampsia, oxidative stress, anaemia, among others (Saedisomeolia and Ashoori, 2018). Riboflavin deficiency occurs in developing and industrialized countries because of insufficient food intake and an unbalanced diet (LeBlanc *et al.,* 2011). Other legumes also have potential. For instance, groundnut (*Arachis hypogaea* L) can be used as condiments. Groundnuts are cultivated through mixed farming with crops such as maize, millet, and root crops. Fermented groundnut, known as *ogiri-ahuekere*, is rich in fermenting bacteria and yeast when fermented for ten days. It competes favourably in the market if processed under good sanitary condition (Chukwu *et al.,* 2019). Therefore, fortifying legume-based fermented foods with riboflavin can help solve malnutrition and address SDGs 2 and 3.

However, there are safety concerns with traditional fermented food products. First is the high contamination risk from fungal mycotoxin, coliforms and food-poisoning bacteria (FAO/WHO, 1996). These microbes will need to be eliminated to ensure that the fermented products are safe for consumption. Secondly, the contamination and cross-contamination from the work environment and utensils used during soaking and washing will need to be overcome with good hygiene. Traditional production practice, which involved crude unhygienic utensils and probably by an unhygienic handler, is common. For instance, in alkaline fermented products, *Escherichia coli* and *Klebsiella pneumoniae* are frequently isolated pathogens (Odunfa and Oyewole, 1998; Olanbinwoninu and Fagunwa, 2021). Hence, one cannot rule out the possible occurrence of pathogenic microorganisms and contamination during production. Thirdly, since salting is often used in some products as preservatives, there is a high dietary salt consumption risk, which may adversely affect health. Food safety organization in each country requires strong food regulation and monitoring to overcome these intrinsic problems. Therefore, there should be an investment in research investigating and remedy safety concerns associated with fermented foods.

Similarly, the handlers should be educated by the food safety bodies on essential microbiology, hygiene, and sanitation as it concerns their products. Monitoring of handlers' compliance will be essential to sustain the food safety interventions. The microbiota in *iru* includes *Firmicutes (Aerococcus, Bacillus, Enterococcus, Lysinibacillus, Staphylococcus), Actinobacteria (Micrococcus)* and *Proteobacteria (Enterobacter, Proteus)* (Ademola *et al.,* 2018). Bacillus genus dominated throughout the processing stage in their phylogenetic studies, but elsewhere specific species - *B. subtilis, B. licheniformis, B. amyloliquefaciens* were proposed as starter culture (Aderibigbe *et al.,* 2011; Adewumi *et al.,* 2014; 2019).

Biofortification of foods via controlled fermentation using culture starters would produce food products with improved vitamin and mineral contents at low cost, which is of particular importance in African countries where the resources of households are often limited. Full biofortification scales up at the country, and Sub-Saharan Africa level will be a cost-effective investment in tackling micronutrient deficiencies in the region and a healthier future.

Another factor in scaling up commercialization and internationalization is the need for studies investigating the entire population of microorganism present (microbiota) in fermented foods and their functions considering all genetic material (microbiome). Such endeavour will allow product optimization that eliminates food pathogens and encourage beneficial probiotics.

Conclusion

The Sub-Saharan African region is home to nearly 1 billion people, and agriculture remains a crucial sector for providing livelihood to most households, and fermented food forms a large portion of the diet. Cassava, maize, and legume are the crops mainly used for fermentation. African fermented foods have both claimed and scientifically proven to provide health benefits. However, many fermented products are yet to be explored scientifically or for their potentials to support achieving the SDGs. The under-researched products include *abacha, akwandu, baobab, cachupu, dengue, emasi, funge, kawal, kingouari, ntsambu, pilipili, togwa,* and *urubu.*

On the other hand, though, products such as cassava dough/flour, maize-based *ogi* and legume-based *iru* condiment are relatively researched. However, barriers such as increase quality substrate yield, safe and hygienic production, food safety, commercialization, and trade still hamper these products. A comprehensive understanding of the microbiota and microbiome of these low hanging fermented foods can be crucial in enabling their full benefits and addressing their implications, such as food safety. Similarly, national food organizations in SSA countries need to pay more attention to traditional fermented foods to ensure high quality, safety, and sustainability optimisation.

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