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REVIEW

Indigenous African fermented dairy products: Processing technology, microbiology and health benefits

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ABSTRACT
Africa is known for its rich, ancient tradition in fermented foods. Among these, fermented dairy products represent one category that is widely consumed, contributing to the socio-economic development and food security of the people. In Africa, traditional food fermentation lends itself as a relatively cheap food processing technology that often improves shelf life/food safety as well as nutrition and health via improvement in the levels of specific micronutrients and the action of probiotics. A range of African fermented dairy products (mainly yoghurt-like products) are produced by spontaneous fermentation, and these fermented dairy products harbor rich and valuable microbial diversity, predominated by lactic acid bacteria and yeasts. Detailed knowledge of the production processes, microbiological and biochemical aspects of traditional African dairy fermentation is critical for the development of products with enhanced quality, safety and health benefits for a sustainable food security in the region. This review therefore provides a comprehensive overview of the traditional African fermented dairy processing technology, as well as technologically relevant microorganisms and health benefits associated with fermented dairy products. Efforts aimed at harnessing the functional food potential of these fermented products could help control some food and health challenges facing many countries in the region.

KEYWORDS
Africa; fermented dairy products; microbiology; functional foods; nutrition; probiotics

Introduction

In many counties in Africa, milk has played a significant economic and dietary role for centuries. These areas (mostly cattle-keeping regions) include North Africa, the Sudanian Savanna regions (Senegal, Gambia, Southern Mali, Burkina Faso, and northern territories of countries such as Guinea, Cote D'ivoire, Ghana, Togo, Benin and Nigeria) and the highlands of East Africa (FAO 1990, 2018). Indigenous and nomadic tribes such as the Fulani, Maasai, Tuareg and Borani have consumed milk since prehistoric times (Ndambi, Hemme, and Latacz-Lohmann 2007). However, due to reason of climate and low income, commercial production of milk in many developing countries in Africa has been growing at a very slow pace (FAO 2018). Also, milk constitutes the most widely consumed animal protein in Africa, but it is consumed in very small quantities (World Bank 2014). Per capita milk consumption in Africa sits at 30 liters per year; compared to a global average of 214 liters per year (FAO 2006). This low level of production and consumption of milk hinders the diversification and development of novel dairy products in Africa. Moreover, the warm climate in Africa makes it challenging to preserve highly perishable food products such as milk, particularly in resource poor communities that lack the necessary processing/preservation (chilling) systems. Fermentation as a processing technology is therefore important in Africa, not only because it serves as a form of preservation, but also meets the need for diversifying products from milk, while helping to improve the functionality, digestibility, as well as nutritional profile of milk and its products. This review gives a comprehensive profile of several traditional fermented dairy products from Africa. An assessment of the microbiology of these products is presented, together with a discussion of the food and health application of these fermented products.

Fermentation as a processing technology in Africa

Food processing technologies are the various set of operations that modify food ingredients and raw materials, with the intention of obtaining products with desired quality attributes that meet nutritional and functional requirements. There are primitive and contemporary food processing technologies including simple processing techniques such as drying, salting, smoking and fermentation. While food processing still has the main objective of providing a nutritious diet, other aspects such as preservation and generation of wealth for producers are added advantages. In Africa, fermentation of food is one of the oldest methods of food processing and preservation and many traditional food

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processing techniques have been handed down from generation to generation for centuries (Nduko et al. 2017).

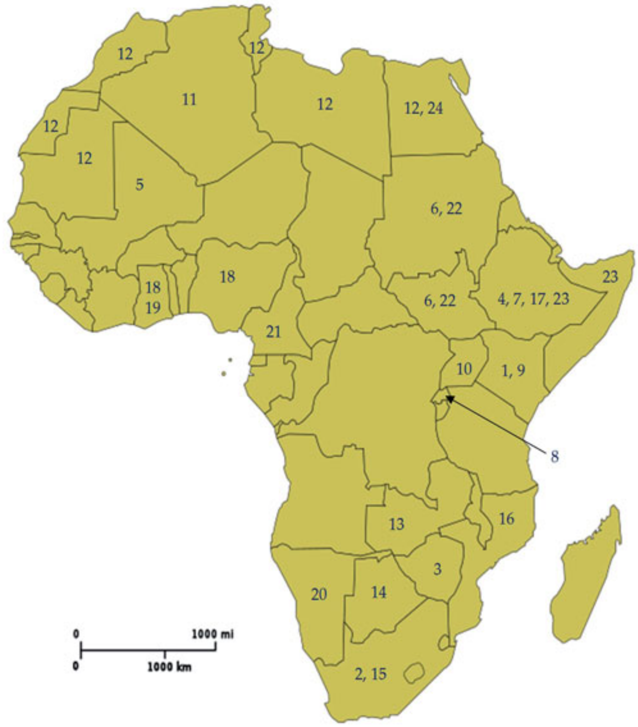
Food fermentation as a processing technology comprises of the alteration of raw materials (food ingredients) into a melange of value-added products by employing the phenomena of microbial growth and their activities on various substrates (MacDonald and Reitmeier 2017). In prehistoric times, foods were fermented with the primary purpose of extending shelf life and enhancing sensory characteristics of the fermented food products (Hui et al. 2004). However, the benefits of food fermentation has expanded to include inhibition of pathogenic microorganisms and improvement in nutritional value or digestibility (Terefe 2016). Typically, food fermentation processes practiced in Africa are mostly spontaneous. Thus, the fermentation do not rely on well-defined starter cultures, durations of fermentation and temperatures are poorly controlled, leading variations in the quality of products (Nduko et al. 2017). Notwithstanding, various fermented food products are produced in different African countries. These fermented foods include alcoholic and nonalcoholic beverages such as palm wine and *pito*, breads, porridges and fermented dairy products including yoghurts and cheeses. These fermented food products are obtained from vegetal raw materials such as starchy root crops, vegetables proteins, leaves and fruits (Marshall and Mejía-Lorío 2011) or animal sources such as fish, meats and milk.

Foods such as *poto poto* (maize) in Congo, *Ogi* (maize, millet) in Nigeria, *Kenkey* and *Banku* (maize) in Ghana and *Togwa* (sorghum) in Tanzania are value added products from fermented cereals (Abriouel et al. 2006; Greppi et al. 2013; Mugula et al. 2003). Legumes and African oil seeds are vegetables that are rich in proteins. Most of these undergo alkaline fermentation resulting in foods such as *Ugba* (African oil bean seed) in Nigeria and *Ogili* (Melon and Castor oil seeds) in East, Central and West Africa (Ogbulie, Nsofor, and Nze 2014; Barber, Achinewhu, and Ibiama 1988). Additionally, cassava is one of the major starchy root crop fermented to elongate its shelf life and reduce cyanide contents for safer consumption (Aworh 2008). *Gari*, *Kivunde* and *Lafun* are value added products of fermented cassava in West and Central Africa, Tanzania and West Africa respectively. Moreover, fish and milk are the major animal protein products that are widely fermented purposely to increase shelf life. *Koobi*, *Momone*, and *Kako* in Ghana (Abbey, Hodari-Okae, and Osei-Yaw 1994); *Lanhouin* in Benin and Togo (Dossou-Yovo 2007) and *Dagaa* in Uganda (Koffi-Nevr et al. 2011) are all value added fermented fish products. *Wagashi* (Ghana) obtained from milk, also called *Warakasi* in Nigeria (Haaland 2007), *jben* and *Iben* (Benkerroum 2013) (northern and eastern Africa) (Aworh 2008), *Mursik* and *Amabere amaruranu* in Kenya (Nduko et al. 2017) and *Amasi* in South Africa (Chelule et al. 2010). Fermented butter such as *Kibe* and cheese (*Areesh* and *Domiati*) are other examples of fermented dairy products in Africa.

Fermented milk products from Africa

Africa is home to a wide range of centuries-old indigenous fermented dairy products that are still consumed, playing significant role in providing key nutrient requirements and income to the people of this region (Asogwa, Okoye, and Oni 2017; Wilson 1988). African Fermented Dairy Products (AFDP) are predominantly yoghurts or yoghurt-like foods and beverages. Depending on country or local region of production, these fermented dairy products with similar or same production methods and final product characteristics may be known by different names. Majority of AFDP are made from cow's milk, but milk from goat, buffalo, camel or ewe are also used in relatively large quantities (Jans et al. 2017; Tamang and Kailasapathy 2010). Prior to the introduction of modern refrigeration in African homes, milk and other raw food commodities were preserved by fermentation (Jespersen 2003; Mensah 1997), a process that likely improved the nutritional quality, safety and digestibility of milk. Generally, food fermentation in Africa occurs spontaneously and takes place at the household level or at a small-scale production site (Caplice and Fitzgerald 1999; Ezeji and Ojimelukwe 1993; Oyewole 1997), although a few products such as *Amasi* in South Africa and *Madila* in Botswana are currently produced on commercial scale (Ohiokpehai 2003; Schutte 2013). Spontaneous fermentation occurs due to the activities of microorganisms inherent in the raw milk, from the environment or processing equipment (Kebede et al. 2007; Oyewole 1997). During the production of fermented dairy products in Africa, milk may be mixed with cereals or other plant materials before or after fermentation to yield unique rich products of cereal and milk-based blends (Franz et al. 2014). The characteristics of African fermented dairy products are often influenced by factors such as the quality and the type of raw milk used, the production methods followed and the regional or local climatic conditions (Mensah 1997; Wouters et al. 2002). Additionally, the production processes of African fermented dairy products are largely dependent on unique recipes handed down from one generation to another. Subsequently, we provide brief descriptions of African fermented dairy products taking into account the similarities or differences that may exist in processing methods and in the final product characteristics.

In Africa, different dairy animals including cow, buffalo, camel, goat or ewe serve as sources of raw milk for the production of fermented yoghurt-like products. Irrespective of the source of milk, a number of fermented dairy products may be produced using similar or slightly different traditional processes. Thus, although several generic names are applied to the different AFDP products, the real number of distinct products may be fewer. For example, *nunu* is a generic name for spontaneously fermented yoghurt-like milk products in northern Ghana (Akabanda et al. 2013; Owusu-Kwarteng et al. 2017). However, very similar products are known by different local names in other parts of West Africa such as *nyamie* in southern Ghana, *fenè* in Mali, *nono* in Nigeria and sour milk in Côte d'Ivoire (Akabanda et al. 2013; Obodai and Dodd 2006; Owusu-Kwarteng et al. 2017; Savadogo et al. 2004; Wullschleger et al. 2013). In other parts of Africa, similar fermented yoghurt-like dairy products include *leben*/*lben* in North Africa (Bensalah, Delorme, and Renault 2009; Mangia et al. 2014), *amasi* and *kefir* in South Africa (Osvik et al. 2013; Witthuhn, Schoeman, and Britz 2004), *suusac* in Kenya and Somalia (Jans et al. 2012a; Njage et al. 2011), *ergo* in Ethiopia (Gonfa et al. 1999), and *gariss* in Sudan



Number	Product name (Countries)
1	Amabere (Kenya)
2	Amasi (South Africa)
3	Amasi (Zimbabwe)
4	Ergo (Ethopia)
5	Fènè (Mali)
6	Gariss (Sudan)
7	Ititu (Ethopia)
8	Kiviguto (Rwanda)
9	Kule-naoto (Kenya)
10	Kwerionik (Uganda)
11	Lben (Algeria)
12	Leben (North African)
13	Mabisi (Zambia)
14	Madila (Botswana)
15	Mafi (South Africa)
16	Masse (Mozambique)
17	Mursik (Kenya)
18	Nunu (Ghana/Nigeria)
19	Nyarmie (Ghana)
20	Omashikawa (Namibia)
21	Pendidaam (Cameroon)
22	Rob (Sudan)
23	Susaac (Kenya/Somalia)
24	Zabady (Egypt)

Figure 1. Pictorial representation of the country of origin for some African fermented dairy products.

(Abdelgadir et al. 2008). The names and origin of some African fermented dairy products are shown in Figure 1.

During the processing of milk into yoghurts in Africa, the freshly collected milk may be sieved or filtered to remove animal fur and other debris that may have contaminated the milk during collection and handling on the farm. Generally, African fermented dairy products are produced from raw (non-pasteurized) or heated (pasteurized) milk. In addition to destroying microbial contaminants in the milk, heating also leads to the denaturation of whey proteins. The denatured proteins together with milk caseins then precipitate at low pH, brought about by lactic acid fermentation, leading to the typical properties associated with yoghurt. For AFDP in which the raw milk is heated, milk fat may be removed prior to fermentation by churning (Figure 2). On the other hand, fat or whey removal may be practiced for non-pasteurized fermented products after the fermentation step to yield varied sets of yoghurt-like products.

An important step in the processing of fermented dairy products in Africa is the fermentation process. AFDP are generally produced by spontaneous fermentation or back-slopping, with fermentation temperatures often reflecting the ambient temperature of the local region where the fermentation takes place. Durations of fermentation varies widely among products, which may be a few hours as occurs in *nunu* in West Africa (Akabanda et al. 2013) or several months, sometimes up to a year, as occurs in the production of *chekapmkaika* (produced from extended fermentation of *Kwerionik*) in Uganda (Schutte 2013). In fact, some of these fermentations can go on for so long that the milk products tend to have very long or indefinite shelf-lives, allowing their use or consumption during the dry seasons when fresh milk is sometimes unavailable (Ørskov 1995; Schutte 2013). A special type of continuous fermentation is reported for *gariss* in Sudan where camel milk is fermented in leather bags made of tanned goat skin, embedded in green or wet grass and then placed on the back of roaming camels leading to continuous shaking by the jerky walk of the camels. Fresh camel's milk is continuously added to the fermenting batch to make up the volume whenever part of the fermented product known as gariss is withdrawn for consumption, and this fermentation practice can continue for several months (Abdelgadir et al. 2008; Abdelgadir, Ahmed, and Dirar 1998; Dirar 1993).

Fermentation vessels for the production of AFDP usually include calabashes, gourds, clay pots, leathers bags or plastic containers. Another important practice during the fermentation of milk in Africa is the smoke pretreatment of fermentation gourds as occurs during the production of *amabere*, *mursik* and *suusac* in Kenya (Jans et al. 2012a; Nieminen et al. 2013; Njage et al. 2011; Nyambane et al. 2014); *pendidaam* and *kindirmou* in Cameroon (Jiwoua and Milliere 1990; Libouga, Ngang, and Halilou 2005; Mbawala et al. 2013); *ergo* in Ethiopia (Gonfa et al. 1999); and *makamo* and *kwerionik* in Uganda (Nakavuma et al. 2012; Schutte 2013). For the production of *kule-naoto* which is very popular among the Maasai community in Kenya, the fermentation gourd made from *Lagenaria siceraria* is gently rubbed with the burning end of a chopped stick of *Olea africana*, a tree locally known as enkidogoe (Mathara 1999; Mathara et al. 2004). On the other hand, *ititu* in Ethiopia is produced by fermenting milk in gorfa, a vessel traditionally woven from fibers of selected plants treated with leaves of *Ocimum basilicum* for both cleaning and imparting desirable flavors to

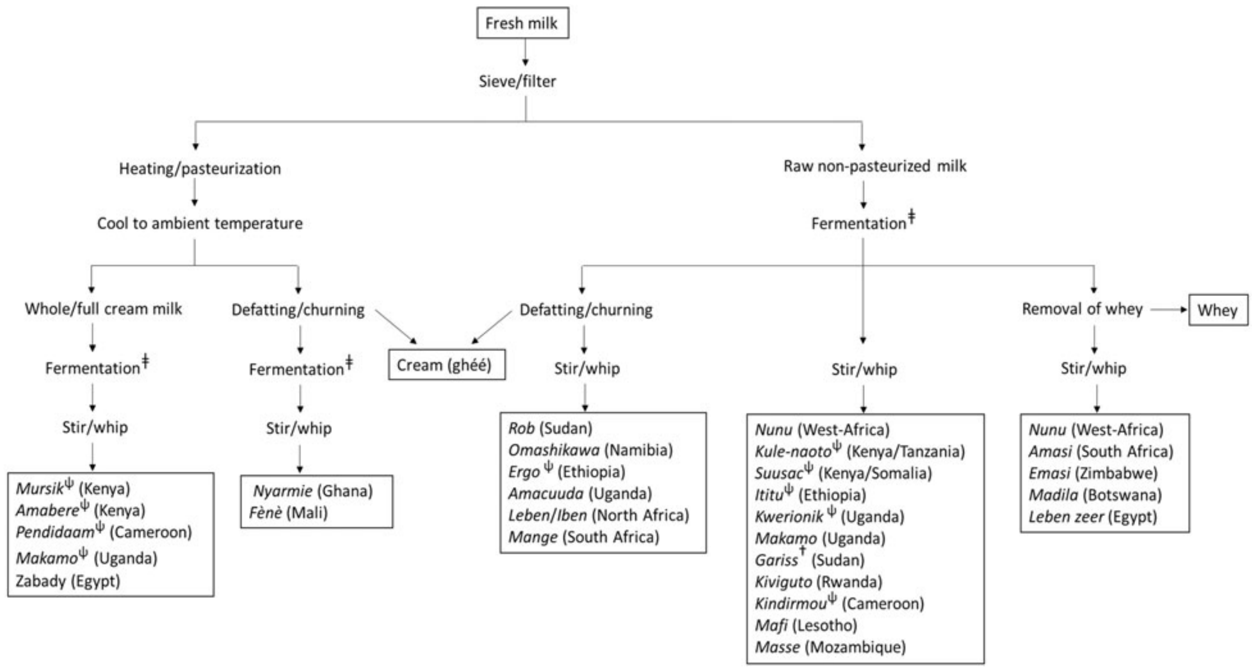


Figure 2. Generalized flow diagram for the production of various African fermented yoghurt-like dairy products (country or region of production). ‡: Fermentation is spontaneous or by back-slopping. Ψ: Product results from fermentation of milk in special smoke treated gourds. †: Product results from semi-continuous fermentation of milk in bags of goatskin hanged on camel's back.

the product, or in a wooden amuyou (Andualem and Geremew 2014; Coppock, Holden, and O'Connor 1991). These pretreatments of fermentation gourds or containers and the selection of particular plant materials as fermentation vessels impart onto the AFDP distinct natural aromas and tastes associated with these products.

African fermented dairy products (with the exception of few cheeses) can generally be considered as stirred type yoghurt. Typically, the gel formed after milk fermentation is gently stirred to obtain a smooth and viscous but still pourable product that is consumed. During stirring, the gel formed break up and lead to the formation of a highly viscous, non-Newtonian liquid product (Jaros and Rohm 2003). There are however, variations in the textural and rheological properties of African fermented yoghurts due to a number of processing factors such as quality of raw milk used, extent of boiling, fermentation time and acidity levels, and the dominant fermentation microorganisms. Similarly, pH and acidity which affect the sensory qualities also vary widely among the various products. For example, the final pH of *nunu* in Ghana can reach as low as 3.0–3.1 (Akabanda et al. 2013) while *amasi* in South Africa or Namibia ranges between 4.0 and 4.5 (Beukes, Bester, and Mostert 2001). Generally, few investigations have focused on the rheological, textural and sensory characteristics of AFDP. However, research geared towards standardizing the rheological, textural and sensory properties of African fermented milk yoghurts is required for product upgrade and consumer acceptability.

Microbiology of African fermented dairy products (AFDP)

The microbiota of fermented dairy products significantly influences the quality, safety and general product characteristics. Therefore, detailed knowledge of the microflora of indigenous African fermented dairy products and their technological roles in fermentation is essential in selecting and defining functional starter culture for improved product quality and safety and overall food security. Microbiological research on African fermented dairy products have been limited to the isolation and characterization of the predominant microorganisms with a few studies focusing on the technological roles of the microorganisms, aimed at developing starter cultures for controlled fermentation. Subsequently, this review will provide a brief overview of the fermentative and technologically relevant microorganisms that have so far been isolated and identified from African fermented milk products.

Generally, production of fermented milk products relies on the old-age traditional process of natural fermentation practiced throughout Africa. Raw or heated milk is allowed to ferment spontaneously, or by 'back-slopping' where a part of a previous batch of a successful fermentation is used as starter to inoculate the new batch (Holzapfel 2002; Josephsen and Jespersen 2004; Owusu-Kwarteng et al. 2017). In such fermentation practices, external factors such as regional or local climatic conditions (season, temperature), quality and composition of the raw material, and the duration of the fermentation process influence the composition and activity of the microbial community during the fermentation (Mathara et al. 2004), which in turn influence the unique organoleptic (Steinkraus 1994) and functional properties of the final products.

The microflora of African fermented dairy products is dominated by mainly lactic acid bacteria (LAB), often associated with yeasts. Table 1 provides an overview of LAB and yeast species isolated from African fermented dairy products. While LAB species are the only group of microorganisms identified so far in some products such as *amasi* (Osvik et al. 2013), *ergo* (Gonfa et al. 1999), *fenè* (Wullschleger et al. 2013), *lben* (Ouadghiri et al. 2009), *ititu* (Kassaye et al. 1991), *kiviguto* (Karenzi et al. 2012), *mabisi* (Schoustra et al. 2013) and *zabady* (El-Baradei, Delacroix-Buchet, and Ogier 2008), both LAB and yeasts have been isolated from several other fermented dairy products such as *amabere* (Nyambane et al. 2014), *gariss* (Abdelgadir et al. 2008), *kule naoto* (Mathara et al. 2004), *lben* (Mangia et al. 2014), *nunu* (Akabanda et al. 2013), *nyarmie* (Obodai and Dodd 2006), *rob* (Abdelgadir, Ahmed, and Dirar 1998; Abdelgadir et al. 2001) and *suusac* (Jans et al. 2012a; Njage et al. 2011).

Among the LAB, *Lactococcus (Lc.) lactis* and its subspecies *lactis* and *cremoris* have been isolated from most AFDP except a few products such as *amabre* in Kenya (Nyambane et al. 2014), *gariss* in Sudan (Abdelgadir et al. 2008) and *ititu* from Ethiopia (Kassaye et al. 1991). In products where *Lc lactis* have been identified, their counts range from about 10^6 to 10^{10} CFU/mL in the final products where they are usually but not always the predominant species (Table 1). The predominance of *Lc. lactis* in AFDP, irrespective of the region or country of production, indicates their adaptability to the prevailing ambient temperatures under which spontaneous fermentations of milk take place in Africa, and thereby contributing to milk fermentation in the region. *Lc. lactis* are widely used as starter culture for dairy fermentations owing to their various technological properties such as high adaptation to lactose metabolism, diacetyl formation and contribution to flavor development and food preservation (Teuber 2009).

In addition to *Lactococcus lactis*, *Lactobacillus* species including *Lb. fermentum*, *Lb. delbrueckii* and *Lb. plantarum* have been isolated among the dominant species in several AFDP with detection levels of 10^8 to 10^{10} CFU/mL (Abdelgadir et al. 2008; Beukes, Bester, and Mostert 2001; Doutoum et al. 2013; Jiwoua and Milliere 1990; Mathara et al. 2004; Nyambane et al. 2014; Obodai and Dodd 2006; Ouadghiri et al. 2009; Witthuhn, Schoeman, and Britz 2004). Other less frequently isolated lactobacilli/coccobacilli in AFDP include *Lb. casei*, *Lb. paracasei, Lb. bulgaricus*, *Lb. helveticus*, *W. confusa*, *Lb. acidophilus*, *Lb. rhamnosus* and *Lb. brevis* (Table 1.). While *Lb. delbrueckii* and *Lb. fermentum* are known to be typical dairy microorganisms, their technological role and contribution to the safety and quality of AFDP has not been fully exploited. However, the widespread predominance of lactobacilli in AFDP across the region is an indication of their adaptation to the local climatic conditions and potential technological role during fermentation of milk in Africa. In an attempt to develop starter cultures for the fermentation of *nunu* in West Africa, Akabanda et al. (2014) evaluated *Lb. fermentum*, *Lb. plantarum*, *Lb. helveticus*, and *Leuconostoc mesenteroides* for various technological properties and further tested the strains as starter cultures in fermentation trials for *nunu* production. The selected *lactobacilli* strains, whether used singularly or in combinations in the fermentation trials, produced *nunu* with highly acceptable consumer sensory characteristics and improved nutritional quality (Akabanda et al. 2014).

Another species of LAB that have recently been isolated in high numbers ($>10^8$ cells/mL) from various AFDP is *Streptococcus infantarius* subsp. *infantarius* (*Sii*). *Sii* were not described as dairy fermentation microbiota until it was first identified as a predominant species in Sudanese spontaneously fermented camel milk, *gariss*, by Abdelgadir et al. (2008). Following this, *sii* has been isolated among the predominant LAB species in other AFDP such as *suusac* in Kenya and Somalia (Jans et al. 2012a; Njage et al. 2011), *fenè* in Mali (Wullschleger et al. 2013), and the Ivorian fermented cow milk (Jans et al. 2017). Since the novel discovery of *sii* in traditional AFDP, further investigations have provided insights into the evolutionary lineages and adaptations of *Sii* to the dairy environment (Jans et al. 2012b, 2013, 2016). As a member of the *Streptococcus bovis/Streptococcus equinus* complex (SBSEC), *Sii* is generally considered as commensal inhabitants of the gastrointestinal tract of animals and humans, and at the same time, opportunistic pathogens, which potentially qualifies them as pathobionts (Chow, Tang, and Mazmanian 2011; Jans et al. 2015; Schlegel et al. 2003). However, the pathogenicity of *Sii* and other novel SBSEC species cannot be very certain, as the methodologies for obtaining most epidemiological data in the past were based on less discriminative biotype classifications as opposed to current taxonomic rearrangements and DNA-based classifications (Jans et al. 2015; Schlegel et al. 2003). In addition to *Sii*, other species of Streptococcus including *S. thermophilus*, *Streptococcus gallolyticus subsp. macedonicus* (*Sgm*), *S. salivarius* and *S. agalactiae* have frequently been isolated from AFDP. Except *S. thermophilus* which is currently approved for use in dairy fermentation by European Food Safety Authority (EFSA 2016), all other species of the genus *Streptococcus* including *Sii* are neither classified by the qualified presumption of safety (QPS) nor have the status of Generally Recognized as Safe (GRAS) (EFSA 2016). However, due to the wide distribution, predominance and adaptation of *Sii* to AFDP, there is the need to further investigate their technological role in dairy fermentation and thoroughly carryout the needed safety assessments to justify their development and use as dairy starter for improved safety and quality of AFDP. A more extensive review on technologically important microorganisms in African fermented dairy products focusing on African *Streptococcus infantarius* variants has recently been published by Jans et al. (2017).

Enterococcus species, although described as contaminants in milk, may play some role during milk fermentation as they have frequently been isolated among dominant organisms in AFDP. *Enterococcus* spp., particularly *Enterococcus faecium* and/or *E. faecalis*, have been isolated from AFDP products such as *fenè*, *kule naoto*, *gariss*, *leben/lben*, *nunu*, *pendidam* and *suusac* (Table 1). Generally, most enterococci are part of the intestinal microbiota of mammals and birds (Ludwig, Schleifer, and Whitman 2009), and their presence in water or food is regarded as an indicator of fecal contamination from animal and human sources (Franz, Holzapfel,

Table 1. Lactic acid bacteria and yeasts isolated from African fermented dairy products.

Product name (country/region)	Identified microflora: LAB species	Identified microflora: Yeast species	Identification methodology	References
Amabere (Kenya)	*Lb. plantarum, Leuc. mesenteroides, S. thermophilus, Lb. bulgaricus, Lb. helveticus, Lb. fermentum*	*Sac. cerevisiae, Trichosporon mucoides, C. famata, C. albicans*	API 50 CH, API 20C AUX	Nyambane et al. 2014
Amasi (South Africa)	*Lc. Lactis, E. faecalis, Lb. casei, Lb. paracasei, Lb. plantarum, Leuc. Pseudomesenteroides, Lc. lactis subsp. lactis, Lb. delbrueckii subsp. lactis, Lb. plantarum, Leuc. mesenteroides subsp. dextranicum*	ND	16S clone library and DGGE. Basic phenotypic characterization, API 50 CH	Osvik et al. 2013; Beukes, Bester, and Mostert 2001
Amasi (Zimbabwe)	*Lc. lactis* subsp. *lactis, Lb. plantarum, Lb. helveticus*	*Sac. cerevisiae, C. lusitaniae, C. colliculosa, S. dairenensis, Dekera bruxillensis, C. lipolytica, C. tropicalis*	Phenotypic methods, API ID32 C test strips	Feresu and Muzondo 1990; Gadaga et al. 1999
Ergo (Ethiopia)	*Lb. mesenteroides*[a], *Lc. lactis subsp. cremoris, Lc. lactis subsp. lactis, Leuc. cremoris, S. thermophilus, Lb. delbrueckii, Lb. homi, Micrococcus spp.*	ND	Basic phenotypic characterization	Gonfa et al. 1999
Fènè (Mali)	*Enterococcus spp., Sii, Lb. fermentum, Lb. plantarum, Lc. lactis subsp. lactis, P. pentosaceus, W. confusa.*	ND	Rep-PCR for clustering, species-specific PCR assay	Wullschleger et al. 2013
Gariss (Sudan)	*Lb. fermentum, Sii, E. faecium, Lb. helveticus;*	*Kluyveromyces marxianus, Issatchenkia orientalis*	rep-PCR for clustering, 16S rRNA gene, rpoB, sodA, gtf sequencing, API 50 CHL, API ID 32C and 26S rRNA gene for yeasts	Abdelgadir et al. 2008
Ititu (Ethiopia)	*Lb. casei* and *Lb. plantarum*.	ND	phenotypic methods	Kassaye et al. 1991
Kiviguto (Rwanda)	*Lc. lactis, Leuc. mesenteroides subsp. mesenteroides Leuc. pseudomesenteroides*	ND	phenotypic methods and sequencing of 16S rDNA and/or 16S-23S rDNA intergenic transcribed spacer (ITS) region	Karenzi et al. 2012
Kule-naoto (Kenya)	*E. faecium, Lb. fermentum, Lb. plantarum, Lc. Lactis, Lb. acidophilus, Lb. casei, Lb. paracasei, Lb. rhamnosus, Leuc. mesenteroides,*	yeasts not identified to genus or species	Basic phenotypic characterization and API 50 CHL	Mathara et al. 2004
Kwerionik (Uganda)	*Lb. plantarum, E. faecalis, Lb. paracasei subsp paracasei, Lb casei subsp casei, Lc. lactis subsp lactis, E. faecium and Leuc. mesenteroides subsp mesenteroides*	ND	Carbohydrate fermentation and other phenotypic tests, ITS-PCR.	Nakavuma et al. 2012; Schutte 2013
Lben (Algeria)	*Lc. lactis subsp. lactis, Lc. lactis subsp. lactis biovar diacetylactis, E. faecalis, Lb. brevis, Lc. lactis subsp. cremoris, Leuc. lactis, Leuc. mesenteroides subsp. dextranicum*	*Kluyveromyces lactis, Sac. cerevisiae*	API 50 CHL, API 20 STREP, API 20C AUX	Mangia et al. 2014
Leben (North Africa)	*E. faecalis, E. faecium, Lc. lactis, S.thermophilus.*	ND	Basic phenotypic characterization, 16S rRNA gene, pepN and pepO sequencing	Bensalah, Delorme, and Renault 2009
Mabisi (Zambia)	*Acinetobacter ursingii, Citrobacter freundii, Lc. lactis, S. equinus, S. thermophilus, E. durans, Lb. brevis, Lb. kefiranofaciens, Lb. plantarum, Leuc. garlicum, Leuc. pseudomesenteroides*	ND	V1–V4 region analysis of 16S rRNA gene	Schoustra et al. 2013
Madila (Botswana)	*Lb plantarum, Lb acidophilus, Lc lactis, Lb fermentum, Lb brevis and Lb delbrueckii*	ND	Basic phenotypic characterization	Ohenhen, Imarenezor, and Kihuha 2013
Mafi (South Africa)	*Lc. lactis subsp. lactis, Lb. delbrueckii subsp. lactis, Lb. plantarum, Leuc. mesenteroides subsp. dextranicum*	ND	Basic phenotypic characterization, API 50 CH	Beukes, Bester, and Mostert 2001
Masse (Mozambique)	*Lc lactis* subsp. *Lactis, Leuc pseudomesenteroides, Leuc lactis, Leuc garlicum*	ND	PCR and DNA sequencing of the 16S ribosomal RNA (rRNA) gene	Schutte 2013
Mursik (Kenya)	*Lb. kefiri, Lb. casei, Lb. paracasei, Lb. rhamnosus, cereus, Lb. brevis, Lb. helveticus, Lb. pontis,*	*C. sphaerica, C. krusei C. kefyr, Sac. fermentati*	16S and 18S rRNA gene sequencing, API 32C AUX;	Nieminen et al. 2013
Nunu (Ghana)				Akabanda et al. 2013

(*continued*)

Table 1. Continued.

Product name (country/region)	Identified microflora: LAB species	Identified microflora: Yeast species	Identification methodology	References
	Lb. fermentum, Lb. plantarum, Leuc. mesenteroides; E. italicus, Lactococcus spp., Lb. helveticus, E. faecium, W. confusa;	*Pichia kudriavzevii, Sac. cerevisiae, C. parapsilosis, C. rugosa, C. tropicalis, Galactomyces geotrichum*	Basic phenotypic characterization followed by GTG-5 fingerprinting and 16S rRNA gene/26S rRNA gene sequencing	
Nyarmie (Ghana)	*Leuc. mesenteroides subsp. mesenteroides, S. thermophilus, Lb. delbrueckii subsp. bulgaricus, Lb. helveticus, Lb. delbrueckii subsp. Lactis, Lc. lactis;*	*Sac. cerevisiae, Candida spp, Trichosporon cutaneum*	16S and 18S rRNA gene DGGE, API 50 CHL, API 20 STREP, API 20C AUX	Obodai and Dodd 2006
Omashikawa (Namibia)	*Lb helveticus, Lb kefiri, Lb casei, Lb rhamnosus, Lb paracasei, Lc lactis* subsp. *Lactis, Leuc pseudomesenteroides, E. faecium, E. durans,*	ND	PCR and DNA sequencing of the 16S ribosomal RNA (rRNA) gene	Schutte 2013
Pendidaam (Cameroon)	Presumptive *Lb. spp*. and Streptococcus/Enterococcus spp.; *Lb. delbrueckii, Lb. helveticus, Lb. fermentum, Lb. plantarum, E. faecalis, E. faecium, S. thermophilus*[c], *Lb. casei, Leuc. mesenteroides, Leuc. paramesenteroides*	ND	Phenotypic characterization	Jiwoua and Milliere 1990; Mbawala et al. 2013
Rob (Sudan)	*Lb. fermentum, Lb acidophilus, Lc. lactis, Strep. salivarius.*	*Sac. cerevisiae* and *C. kefyr.*	ITS-PCR, API 50 CH and the ID 32 API kits	Abdelgadir, Ahmed, and Dirar 1998; Abdelgadir et al. 2001
Suusac (Kenya/Somalia)	*E. faecium, Lb. helveticus, Sii, S. salivarius/thermophilus, W. confusa, E. faecalis, Lb. fermentum, Lc. Lactis subsp. lactis, Leuc. lactis, Leuc. mesenteroides, Lb.curvatus, Lb. plantarum, Lb. salivarius, Lc raffinolactis,Leuc. mesenteroides subsp. mesenteroides*	*C. famata, C. inconspicua, C. lusitaniae, Cryptococcus laurentii, Rhodotorula mucilaginosa, Sac. cerevisiae, Trichosporon mucoides, Trichosporon cutaneum, C. krusei, Geotrichum penicillatum.*	Rep-PCR for clustering, species-specific PCR assay, 16S rRNA gene sequencing Yeasts: API 20C AUX and DNA-based. API 50 CHL and API 20C AUX	Lore, Mbugua, and Wangoh 2005; Njage et al. 2011

Lb., Lactobacillus; *Lc.*, Lactococcus; *Leuc.*, Leuconostoc; *E.*, Enterococcus; *S.*, Streptococcus; *W.*, Weissella; *Sac.*, Saccharomyces; *C.*, Candida; ND, not determined.
[a]*Lb. mesenteroides* is not an official species designation according to DSMZ standing nomenclature.

and Stiles 1999; Godfree, Kay, and Wyer 1997). While *Enterococcus* spp. are frequently detected in dairy products, their status in terms of food safety is quite controversial due to their ability to become opportunistic pathogens (Franz, Holzapfel, and Stiles 1999). Additionally, there are concerns regarding the propensity of fecal enterococci to be resistant to antibiotics, particularly vancomycin, and to transfer such resistant traits via mobile genetic elements (Giraffa 2002; Teuber, Meile, and Schwarz 1999). Therefore, enterococci just like *Sii*, are currently not approved for general application in foods (EFSA 2016). Notwithstanding, *E. faecium* and *E faecalis* preparations have been used as probiotics (Fuller 1989; Tournut 1989).

Leuconostoc mesenteroides and its subspecies *dextranicum* and subspecies *mesenteroides*, and *Leuconostoc pseudomesenteroides* have also been isolated from various AFDP (Table 1). Leuconostocs in dairy fermentation are considered secondary or associated bacteria because they do not bring about significant change in product characteristics when used alone as pure culture (Vedamuthu 2006). However, in co-culture with lactococci and leuconostocs metabolize citrate present in milk to produce diacetyl, thereby impacting on the flavor of the fermented product. Thus, lactococci and leuconostocs act synergistically in generating diacetyl from citrate found in milk. Dairy leuconostocs possess the enzyme needed to metabolize citrate but ferment milk lactose very slowly and are therefore unable to generate the optimum acidic environment necessary for citrate metabolism. On the other hand, the lactococci, which rapidly ferments lactose in milk to facilitate the uptake of citrate by leuconostocs often lack the enzymes needed to metabolize the citrate (Vedamuthu 2006). Thus, diacetyl generation in mixed culture fermentations such as those occurring in AFDP may require the associative activity of lactococci and leuconostocs. Therefore, there is the need to consider leuconostoc-lactococci compatibility when selecting mixed starter cultures for the production of AFDP to generate the needed typical flavors associated with these products.

In addition to the predominant LAB, yeasts are frequently isolated from AFDP with counts ranging from 10^3 to 10^8 CFU/mL of fermented sample. While the fermentation of dairy products in Africa are reportedly predominated by LAB, the associated yeasts could be an essential part of the technologically relevant fermentative microflora. Generally, the role of yeasts in AFDP has been underestimated with most investigations providing partial overview of the microflora of AFDP by focusing only LAB alone or through restricted use of methods to isolate and identify the predominant microflora. Among the few AFDP in which yeasts have been studied, *Saccharomyces cerevisiae* seems to be the predominant yeasts often isolated while *Candida* spp. represent the largest genus, with many products containing more than one species of yeast. Apart from *S. cerevisiae*, there is wide variation in other yeasts species occurring in the different AFDP (Table 1). Representatives of the yeast genera *Candida*, *Cryptococcus*, *Debaryomyces*, *Geotrichum*, *Issatchenkia*, *Kluyveromyces* and *Saccharomyces cerevisiae* are frequently isolated from milk and milk products (Deak and

Beuchat 1996; Quigley et al. 2013). Due to their low pH, yoghurts and yoghurt-like milk products exhibit selective environment for the growth of yeasts (Suriyarachchi and Fleet 1981). During fermentation, yeasts may interact with the fermenting LAB to contribute positively to the fermentation by supporting the growth of the bacteria through the production of essential growth metabolites, such as amino acids and vitamins, or through lactose and galactose metabolism, proteolysis, lipolysis and enzymatic degradation, which contribute to flavor development (Fleet 1990; Jakobsen and Narvhus 1996; Quigley et al. 2013).

Food and health applications of fermented dairy products

Nutritional composition of milk and fermented dairy products

Generally, raw milk is a complex food that contains numerous nutrients, serving as source of lipids, proteins, amino acids, vitamins and minerals. Additionally, milk contains hormones, immunoglobulins, growth factors, cytokines, nucleotides, peptides, polyamines, enzymes and other bioactive peptides and significantly contributes to the body's requirements for calcium, magnesium, selenium, riboflavin, vitamin B12 and pantothenic acid (vitamin B5) (FAO 2013; Haug, Høstmark, and Harstad 2007). Therefore, as a rich source of macro- and micronutrients, milk and fermented dairy products made from them play significant role in human nutrition in developing countries, particularly in parts of Africa where the diets of poor people often lack diversity and consumption of animal-source foods may be inadequate. Throughout the world, milk serves as key source of dietary energy, protein and fat, and contributes on average 134 kcal of energy/capita/day, 8 g of protein/capita/day, and 7.3 g of fat/capita/day, respectively (FAOSTAT 2012). However, the contribution from milk to various nutritional components varies considerably among different regions. For example, it is estimated that milk provides only 3% of dietary energy supply in Africa compared with 8%–9% in Europe and Oceania; 6%–7% of dietary protein supply in Africa compared with 19% in Europe; and 6%–8% of dietary fat supply in Africa, compared with 11%–14% in Europe, Oceania, and the Americas (FAOSTAT 2012).

The nutrient composition of fermented dairy products is largely dependent on the composition of raw milk used, which in turn is affected by several factors including stage of lactation, breed differences, number of calvings (parity), seasonal variations, age and health of animal, feed and management effects including frequency of milking per day and herd size (Bansal et al. 2003; Jenkins and McGuire 2006; Laben 1963; Walker, Dunshea, and Doyle 2004). Due to the number of different factors that affect milk composition, there are difficulties associated with using the available data from literature to draw meaningful conclusions about the nutrient composition of milk of different species because few studies provide detailed information on these factors. Additionally, the multiplicity and variability of analytical methods and study designs can also lead to differences in

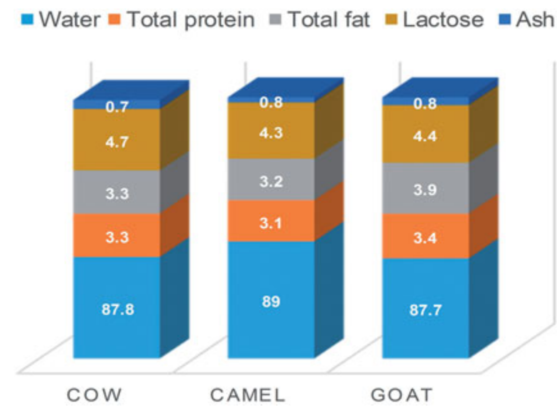


Figure 3. Nutritional composition of cow, camel and goat milk (g/100 g of milk). Source: FAO (2013).

the reports on milk composition. An overview of the proximate compositions of cow, camel and goat milks, which serve as common sources of raw the main materials for the production of various AFDPs is provided in Figure 3.

Generally, milk is considered an important source of protein in the human diet, supplying an average of about 3.3 g, 3.1 g and 3.4 g of proteins per 100 g of cow, camel and goat milk respectively (Figure 3.). Milk protein fractions, both soluble/whey protein and casein proteins, are classified as high-quality proteins in view of human amino acid requirements, digestibility, bioavailability and the essential amino acid score and protein-digestibility corrected amino acid score (Boye, Wijesinha-Bettoni, and Burlingame 2012; Schaafsma 2000). Sulieman, Ilayan, and El Faki (2006) reported the protein content of camel milk for processing *gariss* in Sudan to be about 3.3–4.7%. Similarly, total protein content of fresh cow milk for production of rob was reported to be 3.4–3.8% with an average of 3.5 ± 0.14%, but this value increased to an average of 4.04 ± 0.2% total protein of rob. *Omashikwa* was also reported to have total protein content of about 3.3% (Bille, Buys, and Taylor 2007), while *nunu* was reported to have protein content of 3.2 mg/mL (Nebedum and Obiakor 2007).

During milk fermentation, the proteolytic activity and metabolic activity of LAB can lead to changes in the nutritive characteristics of milk in a manner that is beneficial to the consumer. For example, proteolytic capacities of some LAB during fermentation of milk can result in the release of free amino acids (Pessione and Cirrincione 2016). Muradyan, Erzhynkyan, and Sapondzhyan (1986) reported that fermentation of milk by thermophilic lactic streptococci or acidophilic rods enriched the final products with at least 4 amino acids (cysteine, valine, proline, and arginine). Akabanda et al. (2013) also showed that *nunu* fermented with LAB starter culture can serve as a good source of essential amino acids required in human metabolism.

Milk fat is made up of many different saturated and unsaturated fatty acids, with the actual amounts and composition depending on factors such as animal origin, stage of lactation, ruminal fermentation, or feed related factors. On average, saturated fatty acids (SFAs) constitute about 70% of milk fat fraction while the remaining 30% constitute unsaturated fatty acids (Pereira 2014). Of the many different saturated fatty acids that can be found in milk, only lauric, myristic and palmitic have the property of raising blood cholesterol. Moreover, milk and fermented dairy products contain other essential nutrients, namely calcium, linoleic acid, conjugated linoleic acid (CLA), antioxidants, and probiotic bacteria that have hypocholesterolemic and protective effects (Gurr 1992; Rogeli 2000). Generally, milk and fermented dairy products are a rich source of micronutrients particularly calcium, as well as other elements such as phosphorus, magnesium, zinc, and selenium (Gaucheron 2011). Milk vitamin fraction includes fat soluble vitamins (A, D, E and K) and also the water-soluble vitamins (B complex vitamins) and vitamin C (raw milk) (Gaucheron 2011; Haug, Høstmark, and Harstad 2007). A typical nutritional composition of low fat milk and low fat plain yoghurt (Table 2) shows that the fermentation process contributes to an increase in the variety and concentration of key nutrients, especially the vitamins, minerals and essential amino acids.

Fermented dairy products as source of reduced/lactose-free product

Lactose, the main carbohydrate present in milk, is a disaccharide made up of glucose and galactose. Lactose in milk is found in two isomeric forms, alpha (α) and beta (β). In the small intestine mucosa membrane, lactose is hydrolyzed by the enzyme lactase (also known as β-galactosidase) into two simple sugars glucose and galactose which are absorbed and transported to the liver through the portal vein where galactose is converted to glucose. β-galactosidase activity decreases significantly after weaning in mammals and in some cases may result in deficiency or complete absence of the enzyme lactase in certain individuals. An estimated 70% of adults worldwide are lactose intolerant and develop complications and ill health such as abdominal cramps/pain, bloating, flatulence, meteorism, constipation, and diarrhea upon consuming lactose (Lomer, Parkes, and Sanderson 2008; Schaafsma 2000; Shiby and Mishra 2013). However, fermented dairy products are well tolerated by lactose-intolerant individuals because some of the lactose originally in the milk is converted into lactic acid during fermentation. Additionally, yoghurt cultures are able to release β-galactosidase *in vivo* during digestion in lactose intolerant individuals (Savaiano 2014). The bacterial β-galactosidases are able to survive the acidic conditions of the stomach, as they are physically protected within the bacterial cells and facilitated by the buffering capacity of yogurt (Marco et al. 2017).

Table 2. Typical nutritional composition of low fat milk and yoghurt.

Nutrient	Unit	Low fat milk	Low fat plain yogurt
Proximates			
Energy	kCal (kJ)	42.00 (177.00)	63.00 (265.00)
Protein	g	3.37	5.25
Ash	g	0.75	1.09
Carbohydrate, by difference	g	4.99	7.04
Minerals			
Calcium, Ca	mg	125.00	183.00
Iron, Fe	mg	0.03	0.08
Magnesium, Mg	mg	11.00	17.00
Phosphorus, P	mg	95.00	144.00
Potassium, K	mg	150.00	234.00
Sodium, Na	mg	44.00	70.00
Zinc, Zn	mg	0.42	0.89
Copper, Cu	mg	0.01	0.01
Manganese, Mn	mg	0.00	0.00
Selenium, Se	µg	3.30	3.30
Fluoride, F	µg	2.60	12.00
Vitamins			
Vitamin C, total ascorbic acid	mg	0.00	0.80
Thiamin	mg	0.02	0.04
Riboflavin	mg	0.19	0.21
Niacin	mg	0.09	0.11
Pantothenic acid	mg	0.36	0.59
Vitamin B-6	mg	0.04	0.05
Folate, total	µg	5.00	11.00
Choline, total	mg	17.70	15.20
Betaine	mg	0.60	0.90
Vitamin B-12	µg	0.47	0.56
Vitamin A, IU	IU	47.00	51.00
Vitamin E (alpha-tocopherol)	mg	0.01	0.03
Vitamin D	IU	1.00	1.00
Vitamin K (phylloquinone)	µg	0.10	0.20
Essential amino acids			
Histidine	g	0.10	0.13
Isoleucine	g	0.17	0.29
Leucine	g	0.32	0.53
Lysine	g	0.28	0.47
Methionine	g	0.09	0.16
Phenylalanine	g	0.17	0.29
Threonine	g	0.14	0.22
Tryptophan	g	0.04	0.03
Valine	g	0.22	0.43

Source: USDA (2018).

Fermented dairy products in control of antibiotic use

Fermented dairy product have an extended shelf life compared to milk samples due to the *in situ* production of organic acids, as well as bacteriocins (Silva, Silva, and Ribeiro 2018). Some of these bacteriocins (such as thuricin CD) have been shown to possess narrow spectrum of antibiotics activity (especially on *Clostridium difficile*) and is less harsh in altering the balance of mice gut microbiota, as compared with conventional antibiotics such as metronidazole (Cotter, Ross, and Hill 2013). Fermented dairy products could therefore have applications as a viable option to conventional antibiotics, or be used to complement antibiotic courses, thereby helping to reduce the challenge of antibiotic use that is currently prevalent in most African countries and is exacerbating the global problem of antibiotic resistance (Tadesse et al. 2017).

Fermented dairy products as functional foods

Staying healthy is one of the main reasons that influence the choice of food by consumers (Shiby and Mishra 2013). Beyond meeting basic nutritional requirements, diet may influence many physiological functions and can play detrimental or helpful roles in some diseases (Granato et al. 2010). Therefore, consumers have become very particular about the kinds of food they consume. Conventionally, healthy diet has been linked with foods that are rich in a variety of essential nutrients as well as bioactive components that may have a positive effect on the well-being of the consumer. These class of foods are known as functional foods and these are foods or nutrients whose ingestion leads to important physiological changes in the body that are separate and distinct from those associated with their role as nutrients (Venugopalan, Shriner, and Wong-Beringer 2010). Foods such as conventional foods, modified foods (fortified, enriched, or enhanced), medical foods and foods for special dietary use may all be classified as functional foods (ADA 2009). Sub-classes of fermented dairy-derived functional foods that are discussed in this this review are bioactive peptides, and probiotics.

Bioactive peptides in fermented dairy products

The traditional and contemporary role of milk as the main nutritional subsistence for infants has gone beyond that horizon (Park and Nam 2015). Milk and dairy products have been the main source of nutrients for most mammals and for the growth of children and nourishment of human adults (Park 2009). Additionally, milk possesses a broad range of biologically active compounds that protect neonates and adults from pathogens and illness (Park and Nam 2015). In infants, milk peptides increase the Lactotrope development in pituitary of suckling and Prolactin increases lymphocyte trafficking and immune development. The high levels of calcium play in milk an important role in the development, strength, and density of bones in children and in the prevention of osteoporosis in elderly people. Moreover, other milk components such as phosphopeptides, lactoferricin, casokinins and casoplatelins have are mineral binding, antimicrobial, ACE-inhibitory and antithrombotic activities respectively (Gobbetti et al. 2002; Muro Urista et al. 2011). Bioactive substances are natural constituents in foods that provide health benefits beyond the basic nutritional value of the product (Marsanasco et al. 2015). Some of these bioactive compounds include antibacterial lactoferrin, casomorphins, peptides (including phosphopeptides, immunopeptides), oligosaccharides, antimicrobial proteins, immunoglobulins and lipids, amongst others (Park 2009). The proteinogenic bioactive compounds are readily available in milk, but others are latent and need to be released by the action of proteolytic enzymes (Smacchi and Gobbetti 2000). Proteolytically-derived bioactive peptides (BP) are have a positive influence on physiological and metabolic functions of the body and may have an ultimate beneficial effect on consumers' health (Gobbetti, Minervini, and Rizzello 2007; Kitts and Weiler 2003; Korhonen and Pihlanto 2007; Park and Nam 2015). Milk is one of the most rich sources of these peptides (Korhonen and Pihlanto 2006). Park and Nam (2015) have reported the discovery of a large number of bioactive peptides and biologically and physiologically active compounds from milk casein, whey proteins and other components of milk. These peptides have been shown to have health-promoting properties including antimicrobial, hypocholesterolemic, opioid agonist and antagonists, angiotensin-converting enzyme inhibitory, antithrombotic, immunomodulations, cytomodulation, and antioxidant activity (Hayes et al. 2007; Pessione and Cirrincione 2016; Clare, Catignani, and Swaisgood 2003; Fitzgerald and Meisel 2003; Li et al. 2004). These bioactive compounds are produced in large quantities by the lactic acid bacteria (LAB), the main fermenting microorganisms in AFDP, thereby releasing these bioactive compounds into the fermented products (Pessione and Cirrincione 2016) and enhancing their functional properties. Functional food products that contain these bioactive peptides and milk components are important for the development and improvement of systemic functions, as well as prevention of diet related chronic diseases in both healthy individuals and vulnerable consumer groups (young, old, pregnant and immune deficient individuals). Some of these bioactive peptide sequences obtained via fermentation of dairy products are given in Table 3.

Fermented dairy products as source of probiotics

Probiotics are live microorganisms which when administered in adequate amounts confer a health benefit on the host (Fijan 2014). Probiotic bacteria have dominated most food

Table 3. Some bioactive peptides obtained from fermented dairy products.

Food product	Characteristics (e.g. peptide sequence)	Microorganism used for fermentation	Bioactivity and health impact/ application	References
Fermented milk	Val-Pro-Pro; Ile-Pro-Pro	*Lactobacillus helveticus* LBK-16H	Inhibition of angiotensing converting enzyme (ACE)/ Antihypetensive or blood pressure lowering effects	Nakamura et al. 1995
Fermented milk	Unidentified hydrolysates (possibly Val-Pro-Pro; and Ile-Pro-Pro)	*Lactobacillus helveticus* LBK-16H	Blood pressure lowering effects	Seppo et al. 2003[a]
Fermented milk (yogurt-like product)	Tyr-Pro; Lys-Val-Leu-Pro-Val-Pro-Gln	*Lactobacillus helveticus* CPN4	Antihypetensive activities	Yamamoto, Maeno, and Takano 1999
Sour milk (Calpis)	Unidentified hydrolysates	*Lactobacillus helveticus* and *Saccharomyces cerevisiae*	Blood pressure lowering effects	Hata et al. 1996[a]
Fermented milk	Ala-Arg-His-Pro-His-Pro-His-Leu-Ser-Phe-Met	*Lactobacillus delbrueckii* subsp. *bulgaricus* IFO13953	Antioxidant activities	Kudoh et al. 2001
Curd (*Dadhi*)	Unidentified hydrolysates ranging from di to octapeptides.	Mixed starters including *Lactobacillus bulgaricus* and *S. thermophilus*.	Antihypetensive activities	Dabarera, Athiththan, and Perera 2015
Yoghurts from buffalo, goat and cow milks	Unidentified hydrolysates	Commercial yoghurt samples, fermentation microorganisms were unidentified	Antioxidant and antimicrobial activities	Rahmawati and Suntornsuk 2016
Buffalo milk yoghurt	Hydrolysate containing peptides such as Phe-Val-Ala-Pro-Phe-Pro-Glu; Leu-Val-Tyr-Pro-Phe-Pro-Gly-Pro-Ile-Pro-Lys; Leu-Val-Tyr-Pro-Phe-Pro-Gly-Pro-Ile-Pro-Lys-Ser-Leu-Pro-Gln-Asn; and Leu-Tyr-Gln-Glu-Pro-Val-Leu-Gly-Pro-Val-Arg-Gly-Pro-Phe-Pro-Ile-Ile-Val	Yoghurt starters, together with *Lactobacillus acidophilus* 20552 ATCC, or *Lactobacillus helveticus* CH 5	ACE-inhibitory, antioxidant, and antibacterial activities	Taha et al. 2017

[a]Study involved human subjects.

products including yoghurts and fermented milks for decades due to their perceived health benefits (Mattila-Sandholm et al. 2002). Research indicate that health benefits from both commercial and household African fermented milk such as *mursik* of Kenya are attributed to probiotics used as starter culture (Digo et al. 2017). Probiotic strains such as *Lactobacillus* spp. have also been isolated from non-pasteurized Ethiopia *ergo* (Bereda et al. 2014) and Tunisian *leben* (Samet-Bali 2012).

The use of probiotic bacterial cultures helps stimulate the growth of suitable microorganism, crowds out potentially harmful bacteria, partly due to their ability to produce bacteriocins (Silva, Silva, and Ribeiro 2018), reinforces the body's natural defense mechanism, and improve gut health (Salminen et al. 1999) and also induce antihypertensive and inflammation pain relief effects (Islam 2016; Steinkraus 1994). Moreover, probiotics have been shown in several clinical trials to control radiotherapy-induced diarrhea (Liu et al. 2017), reduce significantly serum cholesterol (Wang et al. 2018), and reduce the levels of plasma ammonia in patients with hepatic encephalopathy (McGee et al. 2011). It is worth noting that most African countries are in the epidemiological transition stage involving an experience of the double burden of both chronic (life-style related non-communicable) and infectious (communicable) diseases (Agyei-Mensah and de-Graft Aikins 2010; Kuate Defo 2014). With proper research and development, probiotics from indigenous fermented dairy products could be used in dietary interventions to help mitigate some of the diseases encountered in this public health challenge.

The mechanisms by which probiotic bacteria exert their beneficial effects is still not completely understood. However, commonly suggested mechanisms underlying the health-promoting effects of probiotics may involve modification of the gut, antagonizing or exclusion of pathogens through production of antimicrobial compounds, competing for pathogen binding and receptor sites and for available nutrients and growth factors, stimulating immunomodulatory cells and producing lactase (Parvez et al. 2006; Franz et al. 2014). Similarly, Stanton et al. (2005), proposed that the mechanisms of action by probiotics are via competitive exclusion, competition for nutrients and/or stimulation of an immune response.

Future outlook and conclusion

According to the World Bank, the consumption of animal-based foods in Africa is increasing; and consumption of milk and its products is projected to grow by 2.3% per year, reaching to 50.2 million tonnes of milk by 2050 (World Bank 2014). This projected growth is good news for the continent since it comes with implications in public health, nutrition, food security and economic growth. However, to harness the full potential of this projection, a number of challenges and unknowns (particularly in the area of production, analysis, and health impact assessment) have to be overcome and deciphered. Firstly, there is the need for investment in applied research aimed at standardizing the production methods of the many fermented dairy products in Africa. The variable quality of most African fermented dairy products resulting from lack of standardization in raw milk quality, lack of the use of defined starter cultures for controlled fermentation processes and microbial contaminations along the processing chain (Aworh 2008; Haaland 2007) need urgent attention. Thus, techniques for assuring the traceability, safety and overall quality of AFDPs need to be developed and implemented. Secondly, analysis techniques for characterizing (i.e. fingerprinting) flavor and sensorial metabolites are needed to profile and standardize the quality characteristics of these of these fermented foods. In this regard, proteomics, metabolomics and genomic techniques as well as multivariate approach to analyze all these data, will be indispensable (El Sheikha and Hu 2018). Thirdly, there is the need for *in vivo* studies and human clinical trials in each region or country to confirm and establish the health benefits and the consequent public health impact following the consumption of the indigenous fermented dairy products. Such *in vivo* health impact assessment is important because the literature is scarce on clinical trials involving indigenous fermented dairy products from African. In conclusion, it is an established fact that fermented dairy products are a storehouse of nutrient, probiotics and bioactive compounds that have a huge impact on human health. In Africa, efforts aimed at harnessing the food and health potential of these fermented products could help control some challenges such as deficiency of essential nutrients (proteins, vitamins, minerals), food security, double burden of chronic and infectious diseases facing many countries in the region.

Conflict of interest

The authors declare no conflict of interest.

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