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Current status on the use of dairy products as carriers of probiotics in Africa: A systematic review

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Abstract

The use of probiotics in African fermented dairy products has notably increased because of their potential to improve nutrition, support gut health, and provide economic benefits to rural and urban communities that rely on fermented dairy for income generation. In many parts of Africa, probiotic-enriched dairy products provide a low-cost dietary intervention in settings affected by high rates of diarrhoea, malnutrition, and limited access to healthcare. These products have demonstrated improved sensory quality, enhanced microbial safety, and health-promoting effects. Despite the growing popularity of probiotics in Africa, there remains limited documentation and research on their adoption and use in dairy products. This systematic review assessed the current application of probiotics in African fermented dairy products and identified trends in product type, regional distribution, probiotic strains, and functional properties. A literature search using AGORA, Google Scholar, Scopus, and Web of Science identified 26 relevant studies. East Africa recorded the highest number of publications (42.31%), followed by Southern Africa (26.92%), West Africa (23.08%), and North Africa (7.69%). The most documented products were yoghurt and sour milk followed by kefir, cheese, infant formula, acid-alcoholic fermented milk, and other locally prepared fermented milk products. Probiotic strains such as Lactobacillus rhamnosus, Lactobacillus plantarum, and Bifidobacterium lactis showed strong acidifying ability, flavour development activity, exopolysaccharide production, and health promoting functions including pathogen inhibition and immune support. A major research gap identified is the limited use of diverse *probiotic strains across the continent and the shortage of in vitro and in vivo validation studies. Overall, the findings show that African fermented dairy products have significant potential as affordable carriers of probiotics that can contribute to improved nutrition, strengthen community livelihoods, and better health outcomes.*

Keywords: Probiotics, Lactic acid bacteria, Traditional dairy products, Commercial dairy products, Africa

Introduction

Sub-Saharan Africa is the region most affected by the HIV pandemic in the world (UNAIDS, 2020) and has the highest infant mortality rate (UNICEF, 2021). People living with HIV and immune-compromised or malnourished children are more at risk of life-threatening diarrhoea (WHO, 2017). Diarrhoeal diseases are the third leading cause of mortality in children under five years old and are responsible for the estimated deaths of 443,832 children annually (WHO, 2024). In sub-Saharan Africa, the recurrence of diarrhoea is one of the main factors that contribute to chronic malnutrition in children under five years of age, leading to stunting and wasting (Mpofu, 2015). Functional foods have emerged as a therapeutic tool to counteract the incidence of infectious diseases and noncommunicable diseases (NCD). There is therefore need for the food industry to integrate nutritional and health-promoting components into these food products.

FAO/WHO (2001) defined probiotics as live microorganisms, which when consumed in adequate amounts confer a health effect on the host. The health benefits of probiotics are attributed to the ability of the microorganism to protect the gastrointestinal tract against colonisation by exogenous microbes (Egbuna & Tupas, 2020). The consumption of probiotics is associated with alleviation of acute rotavirus diarrhoea (Grandy *et al*., 2010), inflammatory bowel disorders, lactose intolerance and urinary tract infections (FAO/WHO 2001; Tamime, 2007). To obtain the desirable therapeutic effects of a product, the viable count of probiotic bacterium should be present over 6 log cfu mL^{-1} at the time of consumption to compensate for the reduction in probiotic viability during passage through the gastrointestinal tract (Marinova *et al*., 2019). Probiotic strains have to meet the requirements associated with the production technology of the product (Cruz *et al*., 2012).

Globally, the proven technological and health benefits of bacterial strains of *Lactobacillus* and *Bifidobacterium* strains have driven exponential growth in the probiotic market. In

Africa, this presents a significant opportunity to develop affordable, culturally relevant functional foods that address local health and nutrition challenges. However, information on the market share and specific characteristics of probiotic dairy products across the continent remains limited. While native fermented dairy products have been part of African diets for centuries, their commercialisation faces hurdles such as the high cost of cultures and inadequate infrastructure (Mukisa, 2016; Ukeyima *et al*., 2010). Although studies have documented the functionality of traditionally fermented milk products (Abdelgadir *et al*., 2008; Franz *et al*., 2014; Mathara *et al*., 2008) and viability of probiotic strains in African fermented products (Brett *et al*., 2021; Mpofu *et al*., 2014; Parker *et al*., 2018), the existing literature is fragmented. A systematic synthesis is lacking on how probiotic dairy products in Africa vary by type, origin, dairy source, fermentation method and probiotic strain, which are the key factors that influence their efficacy, acceptability and scalability. Therefore, this systematic review aims to assess the current status of probiotic use in African dairy products, analyse trends in product types, regional distribution, probiotic strains and their functional properties, and identify key research gaps to inform future research and development.

Methodology

Literature search

A comprehensive literature search was conducted to assess the current status of the use of dairy products as carriers of probiotics in Africa. The review followed the RepOrting standards for Systematic Evidence Syntheses (ROSES) guidelines to ensure methodological rigor and transparency. The search was confined to the period from 1999 to 2021. This timeframe was selected to capture the modern evolution of probiotic research and application in Africa. The year 1999 marks the period when research on African fermented dairy products emerged. Extending the search to 2021 allowed for the inclusion of the most recent developments, including the introduction of low-cost dried probiotic starter cultures and increased documentation of both commercial and traditional fermented dairy products available at the time of analysis.

Search strategy

The literature search was performed across four electronic databases including AGORA, Google Scholar, Scopus, and Web of Science. Grey literature was also identified on organisational websites including the Food and Agriculture Organisation (FAO), World

Health Organisation (WHO) and Yoba for Life. To ensure reproducibility, the full search strings used for each database are as follows:

AGORA: ("dairy products" OR fermented milk") AND ("probiotics" OR "lactic acid bacteria") AND ("Africa" OR "Sub-Saharan Africa")

Google Scholar: "probiotic dairy products in Africa" OR "African fermented milk probiotics"

Scopus: TITLE ABS KEY ("dairy product" OR "fermented milk") and ("probiotic" OR "lactic acid bacteria") AND (Africa OR "African country") AND PUBYEAR > 1998 AND PUBYEAR < 2022

Web of Science: TS= ("dairy product" OR "fermented milk") AND (probiotics OR "lactic acid bacteria) AND (Africa)

The search strategy combined keywords and Boolean operators (AND, OR) as shown. In addition, cross-referencing was used to identify articles on the use of probiotics in traditionally fermented dairy products and commercially fermented dairy products in African regions.

The review was limited to English-language publications, which may have excluded studies published in Francophone and Arabic-speaking regions in Africa. Publication bias was also considered, as there could be bias towards the publication of positive results. To mitigate this bias, grey literature and organisational reports were actively searched. Database searching was combined with cross-referencing to minimise the omission of relevant studies.

Study selection criteria

The selection criteria of titles, abstracts, and full text of searched articles were based on (i) the study type, where articles, reviews and reports were published in a peer-reviewed journal, (ii) geographic focus, where studies conducted in Africa were selected, (iii) content of the research focused on the use of dairy products, (iv) study specifying the type of probiotic strains used in dairy product and the product exhibiting probiotic potential, in the case of traditionally fermented dairy products, and (v) articles published in English. Studies were excluded based on (i) the study focused on non-dairy products, (ii) non-probiotic study, (iii) geographic irrelevance if a study was conducted outside of Africa, (iv) non-peer-reviewed sources of conference abstracts, editorials and articles, (v) duplicate publications.

Screening and quality appraisal

The database searches yielded 123 articles. After removing 37 duplicates, titles and abstracts were screened, resulting in 63 articles retrieved at full text. Thirty studies were excluded at this stage, primarily for geographic irrelevance (n = 14), focus on non-dairy products (n = 3), non-peer reviewed (n=2) or lack of probiotic function (n=11). The methodological quality of the remaining 33 articles was critically evaluated using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Systematic Reviews and Research Syntheses (Aromataris *et al*., 2015). The seven studies excluded had limitations, which included incomplete reporting of sampling methods and limited detail on laboratory analytical procedures in some traditionally fermented product studies. The remaining 26 studies included in the review met the minimum criteria. The studies had clear objectives, appropriate methodology and reporting of results. The ROSES flow diagram for systematic review in Figure 1 indicates the literature search strategy.

Categorisation of identified literature

Data collected from identified articles were extracted, and the information included: author(s), year of publication, type of dairy product, product name, country of origin, type of fermentation (traditional or controlled), dairy source (bovine or non-bovine), probiotic strains used, initial probiotic count and probiotic count at time of consumption.

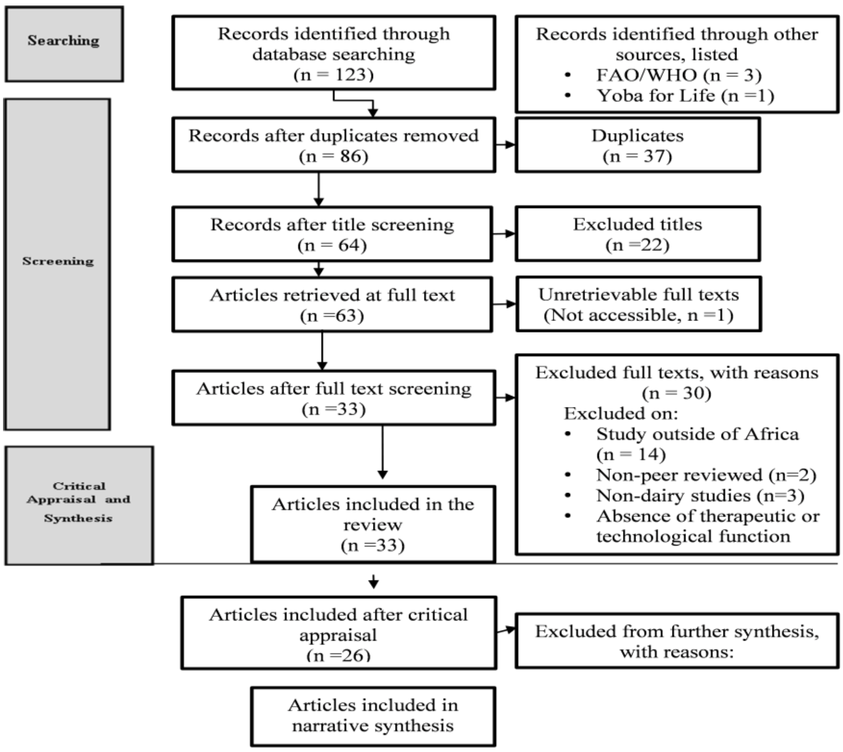
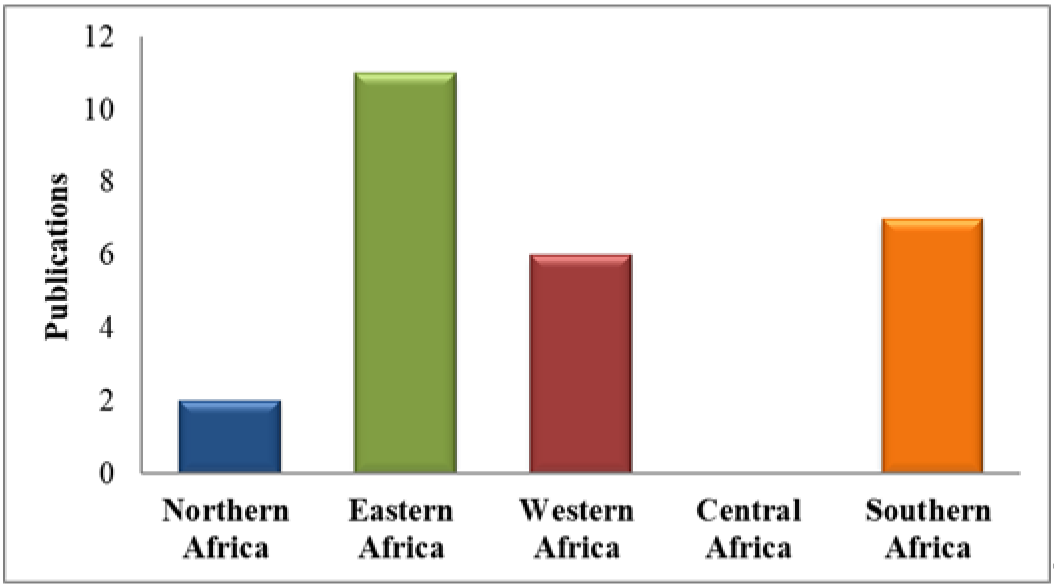


Figure 1: Literature search strategy

Results and discussion

Distribution of the identified articles

The study showed the distribution of published articles on probiotic dairy products in various regions in Africa (figure 2). The highest number of publications amounting to 42.31% (11/26) originated from East African countries such as Uganda, Ethiopia, Kenya, and Tanzania followed by studies conducted in Southern Africa, contributing to 26.92% (7/26) of the articles reviewed. The figure shows that 23.08% (6/26) of the articles originated in Western Africa and the lowest number of articles were recorded from North Africa, with only two articles published in Sudan and Morocco (7.69%). Out of the five regions in Africa, no articles were published in Central African countries. This shows that research on probiotic dairy products is still limited in this region, or this phenomenon can be ascribed to Central Africa being a Francophone region.



The increase in publications in East Africa can be attributed to the rise in community-based projects (Reid *et al*., 2018). Research institutions have been driving research on the incorporation of commercial probiotic strains in fermented dairy products as possible intervention strategies to combat malnutrition and chronic infections as evident in 42% of the articles published in East Africa (Mukisa, 2016; Nduti *et al*., 2016; Westerik *et al*., 2019). Pilot plants producing *yoba* and *fiti* probiotic yoghurts have been established in Kenya, Tanzania and Uganda, thereby leading to increased research on probiotic dairy products (Reid *et al*., 2018).

Southern Africa is the second leading region in publications on probiotic dairy products, with 57% of the articles from the region documenting the use of commercial probiotic strains in products such as *mutandabota* from Zimbabwe, and kefir and infant formula from South Africa (Mpofu *et al*., 2014; Urban *et al*., 2008; Witthuhn, 2004). There has been a relative increase in the dissemination of information on the utilisation of probiotics in southern Africa since 1999 (Gadaga *et al*., 1999). At the same time, the commercialisation of probiotic dairy products is still threatened by several challenges including the lack of industrial funding for the high cost of development of probiotic cultures and lack of infrastructure for storage of these cultures. Despite the unavailability of commercial probiotic strains sourced from Africa, native fermented dairy products with probiotic potential have been documented across Africa and have contributed substantially to the use of dairy products as vehicles for probiotics in the continent (Adesokan *et al*., 2011; Akabanda *et al*., 2014).

Bovine and non-bovine milk sources in Africa

The review identified the sources of bovine and non-bovine milk sources used in the African continent (Table 1), with the bovine contributing a higher percentage at 84.62% (22/26) than non-bovine sources at 15.38% (4/26). Up to date, traditional bovine milk derivatives represent a large ratio of probiotic product innovations (Ranadheera *et al*., 2018). Traditionally fermented dairy products have been derived from bovine milk in cattle-keeping regions in the highlands of East Africa, Sudanian, Savanna, and North African regions (Agyei *et al*., 2020). On the other hand, non-bovine milk from animal species such as goats, sheep, camel, and donkeys has also been consumed in Africa (Agyei *et al.,* 2020). Camel milk was identified as the most documented non-bovine milk source in the production of traditional dairy products that have probiotic potential in the Eastern and Northern regions of Africa.

Several studies characterised probiotic properties of fermented camel milk derivatives, namely *ititu* from Ethiopia (Seifu *et al*., 2012); *suusac* in Kenya (Lore *et al*., 2005); *lben* in Morocco (Ouadghiri *et al*., 2008) and *gariss*, a Sudanese product (Ashmaig *et al*., 2009). Although non-bovine milk sources contribute about 17% of global milk production (Ranadheera *et al*., 2018), the availability of various types of dairy sources could contribute to the diversity of commercial and traditional dairy product types in Africa. Variations in milk composition bring about different characteristics of the product. Therefore, this study identified a gap in limited documentation of probiotic dairy products from non-bovine milk sources in Africa.

Distribution of dairy products based on type of fermentation

The type of fermentation of dairy products was classified into traditional fermentation and controlled fermentation as shown in Tab 1. Identified probiotic dairy products in Africa comprised of 57.69% (15/26) of traditionally fermented products and 42.31% (11/26) of products fermented under controlled conditions. Traditional fermentation of milk has been a result of a shortage of requisite facilities to preserve this highly perishable food product in resource-poor countries (Agyei *et al*., 2020). Natural fermentation is initiated by the complex natural microbiota in milk or through back slopping method in gourds or other fermentation vessels (Nakavuma & Nasinyama, 2012; Seifu *et al*., 2012). Back slopping method which involves the addition of a small portion of previously fermented milk as an inoculum for the next batch has been used in countries across the African continent (Franz *et al*., 2014; Moonga *et al*., 2020). Apart from significantly contributing to food security, nutrition security and socio-economic development of resource-poor countries, dairy products produced by spontaneous fermentation are vehicles of beneficial microorganisms, predominantly lactic acid bacteria (Agyei *et al*., 2020). Challenges in traditional fermentation include variations in the microbial composition of milk which in turn affects product attributes such as taste, aroma and flavour (Moonga *et al*., 2020; Seifu *et al*., 2012). The study also reviewed that spontaneous fermentation of traditional dairy products involved a mixture of LAB and in some studies, the dominant LAB were non-probiotic species such as *Lactococcus lactis* in sour milk (Moonga *et al*., 2020; Nakavuma & Nasinyama, 2012; Osvik *et al*., 2013). On the other hand, controlled fermentation utilised pure probiotic strains as single starter cultures or in combination with the traditional thermophilic starter culture such as *Streptococcus thermophillus* C106 under monitored conditions (Mpofu *et al*., 2014; Mukisa & Birungi, 2018). Other controlled fermentations include single strains of *Weissella Cibaria* NN20 (Nduti *et al*., 2018) or in combination with *Lactobacillus rhamnosus GR-1* (Nduti *et al*., 2016).

Table 1: Overview of fermented probiotic dairy products in Africa

Region	**Primary product types**	**Fermentation type**	**Main dairy sources**	**Most frequently reported probiotic strains**	**Key examples**
East Africa	Yoghurt, sour milk, cottage cheese, locally fermented milk	Predominantly controlled for yoghurt; Traditional for sour milk and indigenous products	Primarily bovine; some camel milk (non- bovine)	*Lactobacillus plantarum*, *L. rhamnosus* (GG, GR-1, yoba 2012), *Weissella cibaria*, *Leuconostoc mesenteroides*, *Enterococcus faecalis*	Yoba for Life yoghurt (Uganda), Fiti yoghurt (Kenya), Amabere amaruranu (Kenya), Kule naoto (Kenya), Kwerionik (Uganda)
North Africa	Sour milk, acid–alcoholic fermented milk	Mainly traditional	Camel milk (non-bovine)	*L. plantarum*, *L. paracasei*, *L. brevis*, *Leuconostoc mesenteroides*, *L. fermentum*	Gariss (Sudan), Lben (Morocco)
Southern Africa	Sour milk, yoghurt-like products, kefir, biologically acidified infant formula	Mix of traditional and controlled	Bovine; Some products non-bovine	*Lactobacillus plantarum*, *L. helveticus*, *L. fermentum*, *Leuconostoc spp.*, *Bifidobacterium lactis*, *Enterococcus faecalis*	Mabisi (Zambia), Mutandabota (Zimbabwe), Amasi (Zimbabwe & South Africa), Kefir (South Africa)
West Africa	Yoghurt, yoghurt-like,	Predominantly traditional for	Predominantly bovine	*L. fermentum*, *L. plantarum*, *L.*	Nunu (Ghana), Dègu (Côte

	sour milk	local products; Controlled for products fermented using commercial probiotic strains		*helveticus*, *L. rhamnosus yoba 2012*, *Leuconostoc mesenteroides*, *Enterococcus faecium*	d'Ivoire), Lait cailé (Senegal), Nono (Nigeria), Fènè (Mali)

Supplementary Table 1: Commercial dairy products and traditional fermented dairy products with probiotic potential identified in Africa

Reference	**Type of fermented dairy product**	**Product name**	**Country of origin**	**Type of fermentation**	**Dairy source**	**Probiotic strains**	**Initial probiotic levels**	**Probiotic levels at the point of consumption**
East Africa								
Chevez & Burton (n.d)	Yoghurt	Yoba for Life probiotic yoghurt	Uganda	Controlled	Bovine	*Lactobacillus rhamnosus* GG	-	9.40 log cfu mL^{-1}
Tesfaye *et al.*, (2011)	Cottage Cheese	Ayib	Ethiopia	Traditional	Bovine	*L. acidophilus* *L. brevis* *L. paracasei ssp paracasei* *L. plantarum*	-	-
Mukisa & Birungi (2018)	Yoghurt	Matooke-based probiotic dairy yoghurt	Uganda	Controlled	Bovine	*L. rhamnosus* yoba 2012	7 log cfu mL^{-1}	9 log cfu mL^{-1}
Nduti *et al.* (2018)	Other locally prepared fermented	Fermented milk	Kenya	Controlled	Bovine	*Weissella Cibaria* NN20	-	-

	milk products							
Nduti *et al.* (2016)	Yoghurt	Fiti yoghurt	Kenya	Controlled	Bovine	*Lactobacillus rhamnosus* GR-1 *Weissella cibaria* NN20	-	-
Nyambane *et al*. (2014)	Other locally prepared fermented milk products	Amabere amaruranu	Kenya	Traditional	Bovine	*Lactobacillus plantarum*, *Leuconostoc mesenteroides*	6.42 log cfu mL^{-1}	8.32 log cfu mL^{-1}
Nakavuma & Nasinyama (2012)	Sour milk	Kwerionik	Uganda	Traditional	Bovine	*Lactobacillus plantarum*, *Enterococcus faecalis*, *Lactobacillus paracasei* subsp *paracasei*, *Lactobacillus casei* subsp *casei*, *Enterococcus faecium* and *Leuconostoc*	9 log cfu mL^{-1} (total LAB)	5 log – 6 log cfu mL^{-1} (total LAB)

						mesenteroides subsp *mesenteroides*		
Seifu *et al.* (2012)	Sour milk	Ititu	Ethiopia	Traditional	Non-bovine (camel)	*Lactobacillus plantarum* *Enterococcus faecalis* *Lactobacillus salivarius*	-	-
Van Tienen *et al*. (2011)	Yoghurt	Probiotic supplemented Moringa yoghurt	Tanzania	Controlled	Bovine	*L. rhamnosus* GR-1	7.85 log cfu mL^{-1}	8.6 log cfu mL^{-1}
Mathara *et al.* (2008)	Sour milk	Kule naoto	Kenya	Traditional	Bovine	*L. acidophilus* *L. paracasei* *L. fermentum* *L. rhamnosus*	7.2 log cfu mL^{-1}	9.2 log cfu mL^{-1}
Lore *et al.* (2005)	Other locally prepared fermented milk product	Suusac	Kenya	Traditional	Non-bovine (camel)	*L. mesenteroides* subsp. *mesenteroides* *L. plantarum*	-	6.8 log cfu mL^{-1}
Northern								

Africa								
Ashmaig *et al*. (2009)	Sour milk	Gariss	Sudan	Traditional	Non-bovine (camel)	*Lactobacillus plantarum* (dominant) *Lactobacillus plantarum*, *L. animalis*, *L.brevis*, *Lactobacillus divergens*, *L. rhamnosus*, *L. paracasei*, *L. fermentum*, *L. alimentarium*	-	-
Ouadghiri *et al*. (2008)	Acid – Alcoholic fermented milk	Lben	Morocco	Traditional	Non-bovine (camel)	*Lactobacillus paracasei*, *Lactobacillus plantarum*, *Leuc. Mesenteroides*, *Leuc. pseudomesenteroides*	-	9.69 log – 10.81 log cfu mL^{-1} (total LAB)

Southern Africa								
Moonga *et al.* (2020)	Sour milk	Mabisi	Zambia	Traditional		*Streptococcus salivarius*, *Lactobacillus helveticus*	-	-
Mpofu *et al.* (2016)	Yoghurt-like	Mutandabota	Zimbabwe	Controlled	Bovine	*L.rhamnosus* yoba	5.5 ± 0.1 log cfu mL^{-1}	9.1 ± 0.4 log cfu mL^{-1}
Mpofu *et al.* (2014)	Yoghurt-like	Mutandabota	Zimbabwe	Controlled	Bovine	*L. rhamnosus* yoba	5.8 ± 0.3 log cfu mL^{-1}	8.8 ± 0.3 log cfu mL^{-1}
Osvik *et al.* (2013)	Sour milk	Amasi	South Africa	Traditional	Bovine	*Lactobacillus paracasei strain KLDS1.0653* *Lactobacillus plantarum strain* *Leuconostoc pseudomesenteroides strain IMAU6000* *Enterococcus faecalis* strain CTC328	-	-

Urban *et al.* (2008)	Infant formula	Biologically acidified milk formula with *Bifidobacterium lactis*	South Africa	Controlled	-	*Bifidobacterium lactis*	-	-
Witthuhn *et al.* (2004)	Kefir	Kefir	South Africa	Controlled	Bovine	*Lactobacillus fermentum* *Leuconostoc lactis,* *Leuconostoc mesenteroides ssp. Mesenteroides*	- - -	6.04 log cfu mL^{-1} 7.62 log cfu mL^{-1} 7.72 log cfu mL^{-1}
Gadaga *et al.* (1999)	Sour milk	Amasi	Zimbabwe	Traditional	Bovine	*Lb. paracasei subsp. paracasei, Lb. plantarum, Lb. acidophilus, Ent.*	-	-

						faecum and *Ent. faecalis*.		
Western Africa								
Brett *et al*. (2021)	Yoghurt	Probiotic fermented dˆeguˆ	Cote d′Ivoire	Controlled	Bovine	*L. rhamnosus* yoba 2012	-	-
Parker *et al*. (2018)	Yoghurt	Lait cailé	Northern Senegal	Controlled	Bovine (milk powder)	*L. rhamnosus* yoba 2012	-	-
Akabanda *et al*. (2014)	Yoghurt- like	Nunu	Ghana	Traditional	Bovine	*Lactobacillus fermentum* (LF-22-16), *Lactobacillus plantarum* (LP-8-2), *Lactobacillus helveticus* (LH-22-7), and *Leuconostoc mesenteroides* (LM-14-11), *Ent. faecium*	-	-
Wullschleger *et al*. (2013)	Sour milk	Fènè	Mali	Traditional	Bovine	*Lb. fermentum, Lb. plantarum,*	-	-

						W. confusa		
Adesokan *et al*. (2011)	Yoghurt-like	Nono	Nigeria	Traditional	Bovine	*L. casei*, *L. fermentum* and *L plantarum*	-	-
Obodai & Dodd, (2006)	Yoghurt-like	Nyarmie	Ghana	Traditional	Bovine	*Leuconostoc mesenteroides* ssp. *Mesenteroides*, *L. helveticus*	-	-

Probiotic dairy products in Africa identified through literature

Owing to the diversity of Africa's food culture, various products were identified as suitable carriers of probiotic microorganisms through a literature search. Figure 3 shows the distribution of product types documented across the continent. In reference to figure 3 yoghurt and yoghurt-like products, 42.31% (11/26) were the most documented product type. Yoghurt products refer to fermented milk produced using standard yoghurt starter cultures, with or without added probiotic strains, while yoghurt-like products refer to traditional or modified fermented milk products that resemble yoghurt in texture, acidity and sensory characteristics. The figure also shows that sour milk products 30.77% (8/26) were the second most documented products. Other product categories such as acid-alcoholic fermented milk, cheese, infant formula and kefir appear in much smaller proportions and contributed 3.85% (1/26) each to the distribution of dairy probiotic product types in Africa. Out of twenty-six publications, 11.54% (3/26) were categorised under other locally prepared fermented milk products. These were identified from articles that cited the product name nevertheless not specifying the dairy product types. This trend confirms that yoghurt-based products remain the most widely studied and utilised probiotic carriers across Africa.

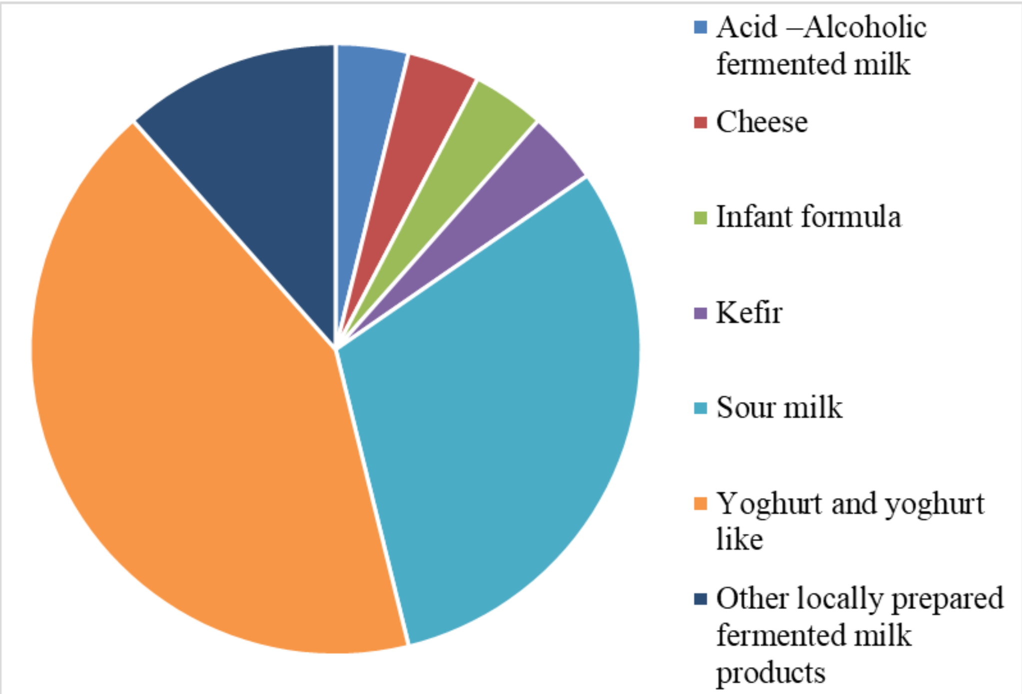


Figure 2: Types of probiotic dairy products identified in Africa

These findings concluded that yoghurt products such as *yoba, fiti, matooke* yoghurt, *lait cailé* and *dˆeguˆ* were identified as suitable carriers of probiotics. Additionally, yoghurt-like products including *mutandabota*, *nyarmie*, *nono* and *nunu* were amongst Africa's most documented vehicles for probiotics. Yoghurt-like products resemble the physical, chemical and organoleptic characteristics of yoghurt. after 24 hours (Obodai & Dodd, 2006). Probiotic yoghurt has become the most acceptable fermented milk product owing to its characteristic attributes which contribute to a positive image among consumers apart from its functional properties (Sarkar, 2018). In a few studies from Tanzania, Uganda and Zimbabwe, indigenous plant-based ingredients were incorporated into probiotic dairy products. The studies have reported an increase in viable probiotic cell counts (Van Tienen *et al*., 2011; Mpofu, *et al*., 2014; Mukisa & Birungi, 2018).

Sour milk products identified through literature include *amasi*, *fènè, gariss, ititu, kule naoto kwerionik* and *mabisi*. Amasi is a popular fermented milk product in southern African countries namely Zimbabwe and South Africa (Gadaga *et al*., 1999). Zambian *mabisi* and Mali’s *fènè* follow a similar protocol as that of *amasi* production leaving a thicker white coagulant with a characteristic sour taste and a cottage cheese-like consistency (Gadaga *et al*., 1999; Moonga *et al*., 2020). Sour milk products such as *ititu* and *gariss* are derivatives of camel milk produced by pastoralists in Ethiopia and Sudan, respectively. In the case of *ititu* fresh camel milk is spontaneously fermented in smoked containers wrapped with a piece of cloth at ambient temperatures (Seifu *et al*., 2012). Moreover, *gariss* is produced by semi-continuous fermentation which takes place in leather bags of tanned goat skin which are entrenched in green grass and are subjected to shaking during movement as they are carried on the bags of the camels. This study revealed that the diversity in culture among ethnic groups in Africa brings about slight variations in the process of making sour milk products.

Some probiotic dairy products such as kefir are less documented in Africa due to limited consumption across the continent. Nevertheless, published articles available on kefir beverages in Africa remain limited except for South Africa contributing to research on the mass cultivation of kefir grains (Witthuhn, 2004). Kefir is a fermented milk beverage produced by a starter culture known as kefir grain that contains complex microbiota including species of lactic acid bacteria, yeasts, acetic acid bacteria and mycelial fungi (Witthuhn *et al*., 2005; Witthuhn, 2004). The review also indicated that research on kefir dates back to nearly two decades ago, showing that no research has been published in recent years. Therefore, there is a need for more research to fill the gap in the functional properties of kefir in Africa. The use of cheese or infant formula as probiotic carriers unfortunately suffers the same fate as kefir in Africa. One article was published on *ayib*, a soft cheese produced from skim milk in Ethiopia (Tesfaye *et al*., 2011). An article was published on infant formulas (Urban *et al*., 2008) and the probable reason for limited documentation is the lack of infrastructure and technologies such as microencapsulation required for the incorporation of viable probiotic strains.

Probiotic species isolated from fermented dairy products in Africa

A quantitative frequency analysis was performed on the probiotic strains documented across the 26 reviewed studies (Table 2). The analysis yielded 53 discrete strain mentions, corresponding 15 bacterial species or 17 distinct strains when commercial variants were specified. The distribution reveals the predominance of *Lactobacillus plantarum,* identified in 13 studies (24.5%), highlighting its ecological adaptability and prevalence in traditional fermentation across the continent. Strains of *Lactobacillus rhamnosus* were collectively the second most frequently reported (17 %), with the yoba variant being the most documented strain within the species. The variant was recorded in 6 studies (11.3%) from multiple regions. This distribution outlines a contrast in probiotic application in Africa where a diverse indigenous microbial ecosystem is dominated by *L. plantarum* in traditional products while *L. rhamnosus* yoba is strategically being used in commercial development of probiotic products.

Table 2: Frequency distribution of probiotic strains identified in studies of African fermented dairy products (n=26)

Rank	***Probiotic Species/*Strain**	***Frequency (Count)***	***Frequency (%)***
1	*Lactobacillus plantarum*	13	24.5%
2	*Lactobacillus paracasei*	6	11.3%
3	*Leuconostoc mesenteroides*	6	11.3%
4	*Lactobacillus fermentum*	5	9.4%
5	*Lactobacillus rhamnosus*	9	17.0%
5a	*L. rhamnosus yoba*	6	11.3%
5b	*L. rhamnosus GG*	1	1.9%
5c	*L. rhamnosus GR-1*	2	3.8%
6	*Lactobacillus acidophilus*	3	5.7%
7	*Enterococcus faecium*	2	3.8%

8	*Enterococcus faecalis*	2	3.8%
9	*Lactobacillus helveticus*	2	3.8%
10	*Weissella cibaria*	2	3.8%
11	*Bifidobacterium lactis*	1	1.9%
12	*Lactobacillus alimentarium*	1	1.9%
13	*Lactobacillus brevis*	1	1.9%
14	*Streptococcus salivarius*	1	1.9%
15	*Weissella confusa*	1	1.9%

Counts represent the number of studies in which each species or strain was reported.

Probiotic species isolated from traditionally (uncontrolled) fermented dairy products

Probiotic species isolated from traditionally (uncontrolled) fermented dairy products in Africa The study revealed that traditionally fermented dairy products contributed to 57.69% of the studies conducted on probiotic dairy products in Africa (Tab 1). This shows that traditionally fermented dairy products with probiotic potential have significantly contributed to the varied diet of most African countries.

Microbial composition

The study indicates that these products are fermented by mixtures of multiple LAB strains, as shown in Table 1. In the genus *Lactobacillus* species identified in the study include *L. acidophilus*, *L. casei*, *L. paracasei*, *L fermentum, L. rhamnosus*, *L. plantarum and L. helveticus* (Fontana *et al*., 2019; Jensen *et al*., 2012; Klein *et al*., 1998). The results revealed that *L. plantarum* is the most dominant probiotic LAB isolated from fermented milk products namely *amasi, amabere amururanu*, *ititu*, *fènè*, *garis*, *kwerionik*, *lben, nono, nunu, ayib and suusac* (Adesokan *et al*., 2011; Akabanda *et al*., 2014; Ashmaig *et al*., 2009). *Lactobacillus plantarum* is the most dominant strain in traditionally fermented dairy products because it possesses an adaptable metabolism that allows it to ferment various carbohydrates, including monosaccharides, disaccharides and polysaccharides that are found in dairy substrates. Strains of *L. plantarum* can ferment galactose, ribose, mannose, mannitol, fructose, sucrose, maltose, esculin, gentiobose among other sugars (Mathara *et al*., 2004).

Other frequently identified probiotic strains including *L. fermentum* isolated from *garis*, *kule naoto* and *nunu*, *L. paracasei* isolated from *amasi*, *garis*, *itutu*, *kule naoto*, *kwerionik* and *lben* and *L. acidophilus* exhibited a viable count of 6 log cfu mL^{-1} to 10 log cfu mL^{-1} (Mathara *et* *al*., 2008; Nakavuma & Nasinyama, 2012; Seifu *et al*., 2012). These findings indicated that the products possess probiotic functions as they met the criterion to have a viable bacterium count above 6 log cfu mL^{-1} (Mpofu *et al*., 2014) thereby conforming to FAO/WHO guidelines (FAO/WHO, 2006).

PCR analysis of naturally fermented products such as *nyarmie* and *nunu* indicated the presence of *L. helveticus* (Akabanda *et al*., 2014; Obodai & Dodd, 2006), nonetheless, falling into the category of less frequently isolated LAB together with *L. alimentarium*, *L. rhamnosus*, *L. Salivarus*, *S. salivarius* and *Leuconostoc* species. Probiotic viable counts of *Leuconostoc mesenteroides* subsp *mesenteroides* were isolated in *suusac* as well as *kwerionik* and *lben* (Lore *et al*., 2005; Nakavuma & Nasinyama, 2012; Ouadghiri *et al*., 2008). *Streptococcus* species such as *S. salivarius* were also identified as probiotic species in traditionally fermented dairy products (Wescombe *et al*., 2012). In the genus *Enterococcus*, Ec. *faecium*, *Ec. faecalis* exhibit probiotic functions (Klein *et al*., 1998). Probiotic *Weisella* species such as *W. confusa* were also identified as probiotic species (Bourdicho, 2021).

Fermentation methods

Fermentation methods used in traditionally processed dairy products play an important role in determining the microbial composition and functional properties of the final products. The review showed that these techniques vary across African regions and are shaped by long standing cultural practices that influence the selection and dominance of probiotic species. A key method is back-slopping, which refers to the practice of using a portion of a previously fermented batch to initiate fermentation of milk. This method promotes the transfer and propagation of a diverse consortium of lactic acid bacteria (Akabanda *et al*., 2014).

In addition, the use of different fermentation vessels and handling practices contributes to the distinct characteristics observed in products. In *suusac* and *kwerionik* the occurrence of probiotic species is influenced by the conditions in the fermentation vessel. The use of smoked gourds or charcoal-treated gourds in the production of fermented milk products creates a selective environment that allows for the growth of desirable LAB with unique functionalities (Lore *et al*., 2005; Nakavuma & Nasinyama, 2012). The natural microflora in dairy milk also affects the process of natural fermentation (Akabanda *et al*., 2014).

Challenges in traditionally fermented dairy products

Although traditionally fermented dairy products in Africa contain diverse probiotic species, several challenges that limit their quality and potential for wider commercial use were identified. Studies on *nyarmie* and *nunu* highlighted the drawback of the use of the back-slopping method, resulting in products with variable quality and stability (Akabanda *et al*., 2014; Obodai & Dodd, 2006).

Safety concerns were also identified in the review. Some traditionally fermented products contained species of genera *Enterococcus* and *Weisella that* have been identified as opportunistic pathogens (Fairfax *et al*., 2014; Wullschleger *et al*., 2013). Strains of *E. faecium* were isolated from *nunu, kule naoto, lben* and *suusac* (Akabanda *et al*., 2014; Mathara *et al*., 2008; Ouadghiri *et al*., 2008). A study in Mali revealed that *fènè,* a sour milk product contained *W.confusa* strain. Therefore, one of the main hindrances to the commercialisation of traditionally fermented dairy products with probiotic potential can be attributed to the lack of safety assessment of probiotic strains found in dairy products in Africa.

Probiotic strains used in controlled fermentation of dairy products

Publications on commercial probiotic strains showed that *Lactobacillus rhamnosus* GG was the most used strain in African countries. Twenty-three percent (6/26) of the studies conducted in Africa utilised the generic probiotic variant known as *Lactobacillus rhamnosus* yoba. Production of yoba yoghurt has been an enormous success in the Eastern parts of Africa namely Uganda, Kenya and Tanzania (Chevez & Burton, n.d; Westerik *et al*., 2018). Other countries including Cote d′Ivoire, Senegal and Zimbabwe have conducted studies on dairy products containing *Lactobacillus rhamnosus* yoba (Brett *et al*., 2021; Mpofu *et al*., 2014; Parker *et al*., 2018). Again, the *L. rhamnosus* yoba strain has increasingly been integrated into native dairy products in Sub-Saharan Africa.

Incorporation of health-promoting probiotics into traditionally fermented dairy products has emerged as a possible solution to combat nutrition insecurity in resource-poor communities, where the prevalence of malnutrition is high (Mpofu *et al*., 2014; Parker *et al*., 2018). *Lait caillé*, a fermented milk product, prepared in wooden bowls known as *lahals* in northern parts of Senegal (Parker *et al*., 2018) and *mutandabota*, a Zimbabwean food product prepared by mixing cow's or goat milk with dry baobab fruit pulp (Mpofu, 2014) were enriched with *Lactobacillus rhamnosus* yoba 2012. The results from the study by Parker *et al*. (2018) indicated a 20 to 60-fold increase in the total viable probiotic count of *L. rhamnosus* yoba. Outcomes of this study were comparable to those depicted from the Zimbabwean study where *L. rhamnosus* yoba thrived in the product and a viable count of 8.8 ± 0.4 log cfu mL^{-1} was recorded at the time of consumption (Mpofu *et al*., 2014).

The second most documented probiotic strain used in Africa was *Lactobacillus rhamnosus* GR-1. Two studies from Kenya and Tanzania showed that *L.rhamnosus* GR-1 was used in *fiti* yoghurt and probiotic yoghurt supplemented with moringa, respectively (Nduti *et al*., 2016; Van Tienen *et al* ., 2011). *Weissela cibaria* NN20 strain was identified in two articles in Kenya (Nduti *et al.*, 2016; Nduti *et al*., 2018). In a study by Nduti *et al*. (2016), the strain was also incorporated into *fiti* yoghurt. After a successful trial, *Weissela cibaria* NN20 was then isolated from a local fermented cereal product known as '*kimere*' and used to produce a fermented milk product. In the case of probiotic *nono* production in Nigeria, pure strains of *L. casei*, *L. fermentum* and *L. plantarum* were used as starter cultures (Adesokan *et al*., 2011). A similar study was carried out in Ghana, where *Lactobacillus fermentum* (LF-22-16), *Lactobacillus plantarum* (LP-8-2), *Lactobacillus helveticus* (LH-22-7), and *Leuconostoc mesenteroides* (LM-14-11), were isolated from a traditional product known as *nunu* for starter culture production (Akabanda *et al*., 2012). The use of probiotic cultures of *Bifidobacterium lactis* was reported in a study on formulas in South Africa (Urban *et al*., 2008). Other probiotic cultures documented including *Lactobacillus fermentum, Leuconostoc lactis* and *Leuconostoc mesenteroides ssp. Mesenteroides* were isolated in kefir grains, which are used to produce kefir beverages (Witthuhn *et al*., 2004).

Overall, *Lactobacillus rhamnosus* strains GG and GR-1 are the most used commercial probiotics across Africa. Two probiotic strains exhibited favourable properties making them suitable for applications in Africa. The innovation of a shelf-stable dried bacterial consortium of either *L. rhamnosus* GG or *L. rhamsnosus* GR-1 with *Streptococcus thermophilus* C106 has given rise to increased studies on probiotics in Africa (Chevez & Burton, n.d; Kort & Sybesma, 2012; Westerik *et al*., 2018). Nevertheless, *L. rhamsosus* GG is the most studied probiotic bacterium with proven health benefits upon oral intake (Kort *et al*., 2015; Westerik *et al*., 2018). The consumption of *yoba* probiotic yoghurt has proven to be beneficial in the prevention of diarrhoea, common cold, skin conditions and allergies in children in Uganda

(Chevez & Burton, n.d) and these characteristics might have led to the increased use of the probiotic culture. On the other hand, *Lactobacillus rhamnosus* GR-1 is the second most scientifically documented *L. rhamnosus* strain (Westerik *et al*., 2018). *L. rhamnosus* GR-1 *fiti* yoghurt has expanded the reach of probiotics in Kenya and Mwanza through social enterprises (Reid *et al*., 2018). Apart from the known health benefits, of these two strains, the successful utilisation in Africa is ascribed to the affordability of both the starter cultures as well as the products. This phenomenon is of utmost importance in resource-poor countries as most probiotic products such as capsules are inaccessible and highly-priced (Westerik *et al*., 2019).

Effect of probiotic strains on technological properties of fermented dairy products

Probiotic strains of lactic acid bacteria (LAB) in fermented dairy products influence the technological properties of yoghurt, including improving textural properties, taste, aroma, and health-promoting properties. This section will delve into the technological properties of probiotic strains in Table 1.

Acidification activity of probiotic strains

The acidity of fermented dairy products is attributed to lactic acid, the primary organic acid produced during fermentation by lactic acid bacteria (Mukisa & Birungi, 2018). The propagation of probiotics in fermented milk products results in the lowering of pH from 6.7 to around 4.3. The acidification properties of probiotics influence their application as primary starter cultures or as adjuncts in starter cultures. For instance, *L. fermentum*, *L.mesenteroides* and *L. plantarum* demonstrated fast acidifying properties in the production of 'nunu' (Akabanda *et al*., 2014). *L. fermentum* is dominant in traditionally processed dairy products in Africa therefore bringing about similar characteristics in these products (Akabanda *et al*., 2012).

Homofermentative bacterium such as *L. plantarum* in *amabere amaruranu* plays a vital role in the development of lactic acid. The study also suggests that the characteristic sour taste is a result of *L.plantarum* activity (Nyambane *et al*., 2014). Homofermentative pathways produce lactic acid as the main product whilst heterofermentative metabolism by LAB produces other by-products such as carbon dioxide, acetic acid or ethanol (Chen *et al*., 2017). Rapid acidification by these probiotic strains is essential in flavour and aroma development of fermented dairy products (Akabanda *et al*., 2014). Another study by Seifu *et al*. (2012)

indicated that *L.salivarius* demonstrated strong acidifying activity in skim milk. On the other hand, the decrease in pH of fermented milk affects propagation and survival of probiotics as in the case of *L. rhamnosus* yoba. The bacterium grows at the lowest pH range of 4.4 to 3.4 (Mpofu *et al*., 2014).

Influence of probiotics on flavour

Flavour and aroma development in fermented milk products is mainly caused by biochemical reactions by lactic acid bacteria. The typical fresh, buttery, sweet and fruity aroma of fermented products such as yoghurt is attributed to carbonyl compounds (C4) compounds namely acetaldehyde, diacetyl and acetoin (Chen *et al*., 2017). These compounds are produced through the glycolytic pathway or citrate metabolism of the genera *Lactococcus, Leconostoc* and *Weisella* (Chen *et al*., 2017). Citrate is the principal precursor of diacetyl in fermented dairy products (Adesokan *et al*., 2011). For instance, the functional significance of *Leuconostoc* spp is to convert citrate to aroma compounds, namely diacetyl and acetoin (Akabanda *et al*., 2012). This characteristic has been significant in traditional dairy products such as *nunu* and *suusac* (Akabanda *et al*., 2014; Lore *et al*., 2005).

However, Gadaga *et al*. (1999) reported that *L.mesenteroides* and *L.plantarum* produced *amasi*, a sour milk product with less consumer preference compared to that produced by *Lactococcus lactis* subsp. *lactis biovar diacetylactis*. In *nono* production *Lactobacillus casei* N18 demonstrated the higher diacetyl content (1.65 g/mL), *Lactobacillus brevis* N15 exhibited the lowest amount (0.9g/mL), whilst a mixed starter of *L.casei* N18 and *L.plantarum* N07 produced the highest quantity of diacetyl (2.40g/mL) (Adesokan *et al*., 2011). Mpofu (2015) attributed the aroma and textural properties of probiotic-enriched *mutandabota* to diacetyl and acetoin produced by *Lactobacillus rhamnosus* GG (LGG).

On the other hand, probiotic strains such as *Weissela cibaria* NN20 indicated weak flavour development in a fermented milk product albeit the viscosity and pH of the product were comparable to that of traditional yoghurt (Nduti *et al*., 2018). Other flavour compounds are derived from the proteolytic activity of probiotic strains such as *L. plantarum* and *L. helveticus* to produce flavour compounds such as amine, ammonia, aldehydes, alcohols, indoles and phenols (Chen *et al*., 2017). Lipid hydrolysis by LAB also gives rise to flavour compounds although its contribution is less significant in products such as yoghurts *(Chen et al*., 2017). In the case of kefir beverage, the distinct flavour is a result of the symbiotic interactions between LAB, acetic acid bacteria and yeasts such as *Saccharomyces, Candida* and *Kluyveromyces* species (Witthuhn, 2004).

Influence of probiotics on texture

Textural properties of dairy products are some of the key factors that influence consumer perception. Probiotic bacteria exhibit functional properties in improving the stability, rheology and texture of fermented dairy products due to their ability to synthesise exopolysaccharides (EPS) (Han *et al*., 2016; Zhi *et al*., 2018). Only one study on probiotic-fermented dairy products in Africa highlighted the significance of exopolysaccharides produced by probiotics. A study by Akabanda *et al*. (2014) revealed that *L. helveticus, L. fermentum, L.plantarum* and *L. mesenteroides* exhibited good exopolysaccharide production capabilities within the range of >100-150μg/mL whilst *Ent. faecium* demonstrated poor capabilities. This goes on to show that the viscosity of traditionally processed dairy products such as *ititu*, *suusac*, *fènè*, *amabere amaruranu* and *nyarmie* may be accredited to the presence of good EPS-producing LAB strains mentioned above.

Although the literature on exopolysaccharide production by probiotic LAB is limited in Africa, exopolysaccharides are applied as thickening, stabilising, gelling or emulsifying agents in food products (Akabanda *et al*., 2014). Nduti *et al*. (2018) found that *Weissella Cibaria* NN20 produced a fermented milk product with good viscosity that was comparable to that of yoghurt produced by traditional yoghurt cultures. This might have been because *Weisella* species are good producers of dextran-like homopolysaccharides (Vasanthakumari *et al*., 2015).

Influence on health

Global studies show similar trends in probiotic functionality, with *Lactobacillus* species, particularly *L. plantarum* reported as dominant microorganism in fermented foods across Europe and Asia, which mirrors their prevalence in African fermented dairy products (Yilmaz *et al*., 2022; Adesulu-Dahunsi *et al*., 2022). In vitro and in vivo studies have been carried out on the health-promoting properties of probiotic strains isolated from both traditionally processed and commercially processed dairy products in Africa.

In addition to the already available literature on functional properties of LGG, Mpofu *et al*., (2016) investigated the antimicrobial properties of yoba *mutandabota* using the five enteropathogens including *Listeria monocytogenes*, *Salmonella* spp., *Campylobacter jejuni*, *Escherichia coli* O157:H7 and *Bacillus cereus*. The conclusive results indicated that after three hours into the potential consumption time of yoba *mutandabota*, none of the tested pathogens were detected (>3.5 log inactivation), resembling the 99.9% inactivation of pathogenic bacteria (Mpofu *et al*., 2016). Evidence from clinical meta-analyses further demonstrates that *Lactobacillus rhamnosus* GG reduces the duration of acute gastroenteritis and prevents acute diarrhoea among children (Szajewska *et al*., Sazawal *et al*., 2006).

Akabanda *et al*. (2014) found out that LAB isolates in *nunu* exhibited antimicrobial effects against *Bacillus cereus*, *Staphylococcus aureus*, *Escherichia coli*, *Listeria monocytogenes*, *Salmonella typhi* and *Pseudomonas aeruginosa* using the agar-well diffusion method. Mathara *et al*. (2008) carried out an in-depth analysis of the functional properties of LAB isolated from *kule naoto*. The study indicated that some isolated LAB strains tested positive for acid and bile tolerance, adhesion to human cell line, antigenotoxic characteristics and resistance to antibiotics. Another study in Kenya indicated that *Weissela cibaria* NN20 in fermented milk products showed the ability to sequester aflatoxin B1 (AFB1) in vitro (Nduti *et al*., 2018). Yilmaz *et al.* (2022) revealed that L. plantarum strains in fermented foods can reduce aflatoxins, which suggests their role in maintaining food safety and preventing spoilage.

Several in vivo studies have been carried out to determine the effects of probiotics in dairy products on human health in Africa. These include probiotic yoghurt on reduction of aflatoxin biomarker in Kenya (Nduti *et al*., 2016), lowering of cortisol using probiotic yoghurt in Cote dʹIvoire (Brett *et al*., 2021), reduction of heavy metals in Tanzania using probiotic yoghurt (Bisanz *et al*., 2014), increase in CD4 counts in people living with HIV in Tanzania (Irvine *et al*., 2010). However, human trials remain limited in Africa due to the high costs associated with randomised control trials (Mukisa, 2016). In 2006 the Food and Agriculture Organisation and World Health Organisation emphasised the need for in vitro tests to predict the ability of probiotics to function in the human body (FAO/WHO, 2006).

Conclusion

This research indicated that a large variety of traditionally fermented dairy products in Africa (15/26) are potential carriers for beneficial microorganisms as evident in the number of viable cells recommended for probiotic products (> 6 log cfu mL^{-1}). There has been an increase in the use of pure probiotic strains over the past two decades, though research on probiotic dairy products is still relatively low in Africa (11/26). A total of seven dairy product types were identified from studies conducted in Africa. The findings of this study also revealed that the characteristics of the dairy products identified vary with the methods of fermentation used, the microbial composition, the type of dairy source and the geographical location. The study also revealed that access to probiotic cultures for fermentation increases shelf life and microbial safety, reduces spoilage through controlled fermentation, and increases health properties by delivery of beneficial bacteria in both traditional and commercial dairy products in Africa

Recommendations

Despite the successful utilisation of *Lactobacillus rhamnosus* strains in dairy products, further research is required on the application of other probiotic strains in Africa. This can be achieved by modification of other probiotic strains to meet the conditions in Africa. Isolation of probiotic strains from traditionally fermented dairy products for potential use as starter cultures can be a possible solution in increasing the use of probiotics in Africa. There is also a need for increase of in vitro and in vivo assay for validation of species derived from traditionally fermented dairy products that exhibit probiotic functions. There are untapped areas of research such as the incorporation of probiotics in products such as cheese and ice creams to boost the immunity of customers.

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