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REVIEW ARTICLE

Potential of probiotics from fermented cereal-based beverages in improving health of poor people in Africa

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Abstract Milk and milk products; particularly yoghurts have almost exclusively been used as media for probiotic delivery to human being for a very long time. Despite health benefits such products have to humans; that include supply of nutrients, prevention and cure of certain communicable and non-communicable diseases; the presence of allergens, increased lactose intolerance, hypercholesterolemia effects, the need for vegetarian probiotic products, cultural food taboos against milk, and religious beliefs have led to limitations on the use of milk and its products as probiotic vehicles in many places including Africa. Such limitations have led to more researches worldwide on alternative delivery media for probiotics in order to meet the food preferences and demands of people affected by milk and milk products. An integrative approach has been used to find common ideas and concepts from different studies. Different food matrices have been tested for their ability to carry probiotics and cereals and cereal products have been found as among suitable substrates for the purpose. Some investigations have revealed that traditional African fermented cereal-based beverages are potential probiotic carriers because of the probiotic *Lactobacillus* spp. and yeasts which are involved in the fermentation of such products. This offers an opportunity for the African cereal beverages to be used to provide probiotic health benefits to the majority of African populations. Thus, this review provides information on probiotics including sources, types, health benefits, vehicles for their delivery and specifically also on challenges and future prospects for cereal-based probiotics development and consumption in Africa.

Keywords Fermentation · Cereal-based beverage · Lactic acid bacteria · Probiotics

Introduction

Probiotics is a term coined by Lilley and Stillwell in 1965 to refer to substances secreted by one microorganism which in turn invigorates the growth of another (McFarland 2015; Vijaya Kumar et al. 2015; Iqbal et al. 2014). The term was derived from Latin and Greek; simply meaning "for life" (Kandylis et al. 2016; Iqbal et al. 2014).

The Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO) joint Working Group defined probiotics as "live microorganisms which when administered in adequate amounts confer a health benefit on the host" (FAO/WHO 2002; Gil-Rodríguez et al. 2015; Marsh et al. 2014; Murevanhema and Jideani 2013; WHO 2001).

Probiotics have been used by human beings from time immemorial even before the discovery of microbes. Ancient Egyptians and Tibetan nomads had used fermented milk products and fermented yak milk, respectively (McFarland 2015; Fisberg and Machado 2015; Parker-Pope 2009). However, in the 1800s scientists began noticing the health effects of consuming fermented milk but no reason

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was given. During the same period a renowned scientist Louis Pasteur discovered bacteria and yeasts inducing fermentation in milk but he was unable to describe the health effects they impart in the human body (McFarland 2015; Fisberg and Machado 2015). It was only Elie Metchnikoff who in the 1860s was able to link the number of years the Bulgarians live to the presence of lactobacilli in the gut and the fermented milk they consume (McFarland 2015; Fisberg and Machado 2015). Henry Tissier; in 1906 was able to isolate *Bifidobacterium* from an infant. It is reported that thereafter probiotic candidates have been isolated from a variety of sources which include soil, dairy products, fruit surfaces, and samples of human stool (McFarland 2015; Fuller and Fuller 2011).

Human studies in 1922 and 1932 involving the use of *Lactobacillus acidophilus* established the positive health effects in patients with chronic constipation, diarrhea, and mental disease. In the same time period (1930s); yoghurt starter culture *(Lactobacillus bulgaricus* and *Streptococcus thermophilus)* was abandoned in favour of *Lactobacillus acidophilus* due to inability to colonize the human intestine (McFarland 2015; Fisberg and Machado 2015). In the 1940s; microbiological research focused on identification of pathogenic bacteria rather than probiotic strains of bacteria or yeasts. The focus of research on beneficial microbes from the 1950s to 1980s centered on screening potential probiotic strains isolated from nature and human being as well. The modus operandi for probiotic strains was also defined (McFarland 2015; Fuller and Fuller 2011). Further research on probiotic strains shed more knowledge on the complex interactions of colon flora and their bactericidal actions against colonization by pathogenic bacteria (McFarland 2015; Fuller and Fuller 2011). More effective research on probiotics was started in the decade 1980–1989 through clinical trials, and by 1990–1999 the research resulted into a few hundred publications. The study of probiotics gained momentum from the period 2000 to 2014 during which there was an increase in the number of publications reaching 1476 in 2014 alone compared with 176 in 2000 (McFarland 2015; Fuller and Fuller 2011).

Lactobacillus and *Bifidobacterium* are the two genera of Lactic acid bacteria (LAB) from which most of the known probiotic species belong (Blandino et al. 2003; Nyanzi and Jooste 2012; Charalampopoulos et al. 2002; Tur and Bibiloni 2016; Gil-Rodríguez et al. 2015; Kandylis et al. 2016). Other genera to which probiotic LAB belong are *Lactococcus, Leuconostoc, Enterococcus* and *Streptococcus* (Mokoena et al. 2016). Probiotic microorganisms should be adequately and regularly ingested to a threshold value of 10^6 cfu/ml per serving for maintenance of intestinal microbiota as well as impart the health benefits to the consumer (Mokoena et al. 2016; Nyanzi and Jooste 2012; Peres et al. 2012; Shori 2016). In recent years, the World Gastroenterology Organization reaffirmed that the efficacy of probiotics is strain-specific and dose-specific (McFarland 2015). Despite the numerous health benefits probiotics have on human beings; milk and milk products have been almost exclusively used as delivery vehicles compared to other food substances (Bansal et al. 2015; Nyanzi and Jooste 2012; Salmerón 2017; Vasudha and Mishra 2013). However, milk and milk products have limitations on some segments of the consumer market giving rise to research on alternative food carriers such as cereals (Nyanzi and Jooste 2012; Vasudha and Mishra 2013; Simonson and Salovaara 2011; Rivera-Espinoza and Gallardo-Navarro 2010). This review highlights potential cereal-based probiotic beverages from fermented beverages in Africa; the health benefits of cereal-based probiotic beverages for African populations and what has been done in the development of fermented cereal-based probiotic beverages in Africa.

Types of probiotics

In 2014, three broad categories of probiotics were defined (McFarland 2015). However, selection of probiotic product largely relies on type of bacteria and kind of anticipated beneficial health effect (Iqbal et al. 2014). Table 1 summarizes the broad categories of probiotics.

Potential probiotic strains must be screened to get the ones which can survive the GIT environment. Normally, probiotics candidates should survive as they move to the target organ, able to intact with the immune system, able to kill pathogenic bacteria, safe for human consumption, and industrially advantageous (Enujiugha and Badejo 2017; Gil-Rodríguez et al. 2015; McFarland 2015). Animal models and human volunteers are used in evaluating the kinetics, oral dose recovery, adherence to mucosal layer and persistence in the complex GIT environment (Mokoena et al. 2016). When identification of potential probiotic strain is done, in vivo or in vitro studies may follow to test resistance to gastric and bile acidity (Derrien and van Hylckama Vlieg 2015; Mokoena et al. 2016).

A good probiotic strain with high functionality must be acid tolerant, bile tolerant, oxygen tolerant, heat tolerant, ability to grow in food substrate and being able to metabolize prebiotics effectively as well as being appropriate for large-scale industrial production (survive food processing and storage conditions) (Gupta and Bajaj 2016). In practice, microencapsulation, oxygen-impermeable containers, incorporation of nutrients, and use of stress-resistant strains are employed to enhance the quality and functionality of probiotic strains (Mishra and Mishra 2012). Consequently, a number of probiotic strains have found their way into the

Table 1 Categories of probiotics

S. no	Type of probiotics	Role	References
1	Generally regarded as safe (GRAS)	Not associated with any health claims; e.g. *Lactobacillus bulgaricus* and *Streptococcus thermophilus* used in fermentation of milk	McFarland (2015) Di Stefano et al. (2017)
2	Food supplements	Associated with health claims; e.g. *Lactobacillus rhamnosus* GG used to improve normal colonic flora	McFarland (2015)
3	Drugs	Curing of diseases; e.g. *Lactobacillus acidophilus* capsules used to cure acute pediatric diarrhea	McFarland (2015)

market through extensive screening and testing for their efficacy.

Probiotics products available in Africa

Information available on the market share of probiotics is very limited. However, in global terms the market share in Africa is minimal (Franz et al. 2014; Mukisa 2016; GrandViewResearch 2018). Some sort of a well-established market can be seen in South Africa where products on sale are encapsulated probiotic supplements, fortified food (e.g. baby cereals) and probiotic dairy products (Franz et al. 2014). In Tanzania where this review was done; literature does not show noticeable consumption of probiotics in any delivery media. The only effort to use probiotics in Tanzania was done by the WHE (Western Heads East) project at Mabatini, Mwanza region in 2004 through use of probiotic yoghurt to treat victims of HIV/AIDS (Reid 2010) as well as the study by Willumsen et al. 1997 of managing acute diarrhea in children by use of fermented and amylase-digested weaning gruel. This indicates that knowledge and awareness of the existence of probiotics and presence of probiotic products in most of the African countries is very minimal.

Cereals used for production of African beverages

The major cereal grains used for making African non-alcoholic and alcoholic cereal-based beverages are sorghum (*Sorghum bicolour (L.) Moench*), pearl millet (*Pennisetum glaucum* (L.)), finger millet (*Eleusine coracana*) and maize (*Zea mays* (L.)) (McFarland 2015; Mugula et al. 2003). Nyanzi and Jooste (2012) and McFaraland (2015) have dealt extensively with the traditional African cereal-based beverages by indicating the raw materials, names of the beverages in the location they are found, whether they are non-alcoholic or alcoholic beverages, and the respective technologies used in making such beverages. Whole grain cereals and cereal components provide an option of having probiotic vehicles with double-advantage of giving healthful bioactive components and fibers (Enujiugha and Badejo 2017; Lamsal and Faubion 2009; Waters et al. 2015). Such components include non-digestible carbohydrates, soluble fiber, and phytochemicals such as phytoestrogens, antioxidants, phenolic compounds, phytic acids etc. (Lamsal and Faubion 2009; Waters et al. 2015).

Despite being the main source of dietary nutrients globally, cereal grains lack some basic food components such as amino acids (Amadou 2011; Marsh et al. 2014). Fermentation may improve the nutritional value, sensory attributes and functional qualities of cereals (Amadou 2011; Navarrete-Bolaños 2012).

Cereal based traditional beverages in Africa

Traditionally, cereal based beverages (non-alcoholic and alcoholic) in Africa are prepared through spontaneous fermentation. *Lactobacillus* spp. and yeasts are mainly involved in this kind of fermentation (Aka et al. 2014; Mugula et al. 2003a, b). Spontaneous fermentation involves two stages; lactic acid fermentation induced by a variety of environmental microorganisms and alcoholic fermentation initiated by dried yeast or a portion of previous brew (Olasupo et al. 2010). It improves the preservation, nutritional value and sensory characteristics of the beverages (Aloys and Angeline 2009; Olasupo et al. 2010). Lactic acid fermentation produces non-alcoholic beverages whereas lactic acid and alcoholic fermentations give rise to alcoholic beverages (Kohajdová 2016). Table 2 gives some examples of traditional African cereal beverages.

Microbes taking part in spontaneous fermentation of traditional cereal beverages

Production of African fermented cereal beverages involves competition among various species and strains of microbes and those best suited for the environment will multiply rapidly and dominate certain stages of the process (Aka

Table 2 Typical examples of African cereal beverages

Beverage	Type of beverage	Country	References
Obushera	Non-alcoholic	Uganda	Franz et al. (2014)
Kanun-zaki	Non-alcoholic	Nigeria	Franz et al. (2014)
Pito	Alcoholic	Ghana, Nigeria	Blandino et al. (2003)
Busaa	Alcoholic	Kenya	Aka et al. (2014)
Mahewu	Non-alcoholic	South Africa	Blandino et al. (2003)
Tchapalo	Alcoholic	Côte d'Ivoire	Aka et al. (2014)
Umqombothi	Alcoholic	South Africa	Mokoena et al. (2016)
Borde	Non-alcoholic	Ethiopia	Enujiugha and Badejo (2017)
Gowé	Non-alcoholic	Benin	Aka et al. (2014)
Togwa	Non-alcoholic	Tanzania	Mugula et al. (2003a, b, c)
Tchoukoutou	Alcoholic	Togo, Benin	Aka et al. (2014)
Mangisi	Non-alcoholic	Zimbabwe	Nyanzi and Jooste (2012)
Koko sour water	Non-alcoholic	Ghana	Aka et al. (2014)

et al. 2014; Oyedeji et al. 2013). Lactic acid bacteria are involved in lactic fermentation whereas yeasts are involved in alcoholic fermentation (Todorov and Holzapfel 2014). Lactic acid fermentation induces advantageous characteristics observed in fermented foods. A number of studies have shown that lactic acid bacteria and yeasts are predominant in these beverages (Aka et al. 2014; Enujiugha and Badejo 2017; Guyot 2012; Mugula et al. 2003a; Oyedeji et al. 2013). However, majority of microbes isolated from fermented cereal beverages are LAB (Oyedeji et al. 2013; Mokoena et al. 2016; Kohajdová 2016). In the mash prior to spontaneous fermentation LAB present include *Lactobacillus, Pediococcus, Leuconostoc* and *Enterococcus*. In traditional sorghum beer the microbes normally found belong to the genus *Lactobacillus, Leuconostoc, Lactococcus, Enterococcus* and *Streptococcus*. Typical examples are *Lactobacillus plantarum, Lactobacillus brevis, Lactobacillus casei, Lactobacillus sakei, Lactobacillus acidophilus, Lactobacillus delbrueckii, Lactobacillus fermentum, Lactococcus lactis subsp. lactis, Lactococcus raffinolactis, Leuconostoc mesenteroides subsp. mesenteroidesetc*. The above results are based on conventional bacteriological techniques. Species or strains of *Lactobacillus* are mostly heterofermentative (Hammes and Hertel, 2009). It has also been reported by Enujiugha and Badejo (2017) that *Lactobacillus fermentum*, *Lactobacillus plantarum, Pediococcus pentosaceus, Weisella confusa,* and *Lactobacillus rhamnosus* have been isolated from a traditional fermented maize porridge (sweetened beverage) in Kenya known as Ikii.

Yeasts of the genus *Saccharomyces* are predominant in alcoholic fermentation (Aka et al. 2014; Ray 2005). However, some researchers using molecular biology techniques have indicated that strains of *Saccharomyces cerevisiae* exclusively predominate fermentation of sorghum-based African beverages (Lara-Hidalgo et al. 2017). Despite their importance in food fermentations; only one yeast species *Saccharomyces cerevisiae* subsp. *boulardii* has been found to be probiotic (Gil-Rodríguez et al. 2015).

Why African fermented cereal beverages are produced?

The beverages are produced through fermentation of germinated cereals such as maize, millet and sorghum. In Africa some importance is attached to these beverages. They are important to individuals, families and the society as a whole. Socially, when served; they show a gesture of hospitality, friendliness and also to strengthen amicable relationships between individuals (Aka et al. 2014). They are also consumed in farm work, ceremonies such as marriage and funerals and as supplement food; weaning food for babies (health giving drinks). The beverages also improve lactation in nourishing mothers and prevent coronary diseases and cancer. They are consumed by all social classes. Non-alcoholic beverages are guzzled by all age groups; infants, children, pregnant women, the old and sick people. Alcoholic beverages are mainly consumed by men (Kalui et al. 2010; Aka et al. 2014). The African fermented cereal beverages are also consumed as food or drink. They provide energy in the diet (starch, sugars, proteins) and valuable nutrients such as B-group vitamins; thiamine, niacin and riboflavin as well as vitamin C (particularly in sorghum beverages). They are also sources of minerals like iron, calcium, potassium, magnesium, manganese, phosphorus and copper (Kohajdová and Karovičová 2007). Economically, sale of fermented cereal beverages provide income to households particularly women.

Fermentation improves palatability, aroma, flavor and taste to cereal beverages as a result of production of organic acids and volatile compounds such as lactic acid, acetic acid, propionic acid and acetaldehyde during the process (Kohajdová and Karovičová 2007; Sahlin 1999; Stepanek 2015). It has been reported (Mugula et al. 2003a, b, c) that despite fermenting the cereal gruel during togwa production; LAB participate in proteolytic activities in togwa to give free amino acids and smaller peptides which are utilized by them to produce metabolites. Most of the African fermented cereal beverages are characterized by their colours, taste, odours and flavours, consistency, shelf-lives and alcohol content. The colours of the beverages can be pinkish-brown, whitish-grey to brown, light brown, creamy or milky (colour of raw materials). The beverages have sweet–sour taste, sweet–sour odours and flavours as well as being opaque with suspended microbes and solid particles. Furthermore, they lack or have low level of alcohol and their shelf-lives are shorter (Aka et al. 2014; Aloys and Angeline 2009; Kitabatake et al. 2003; Oyedeji et al. 2013; Mukisa et al. 2016, 2017; Mokoena et al. 2016). In most cases consumption of traditional African fermented beverages is done in the fermenting state; as such organoleptic qualities vary.

African fermented cereal beverages have prolonged shelf-lives because fermentation produces organic acids such as butyric, propionic, lactic as well as acetic acids which lower their pH to below 4 and consequently inducing inhibitory effects to growth and proliferation of both spoilage and pathogenic microbes (Mugula et al. 2003c). Anti-microbial metabolites (e.g. carbon dioxide, ethanol, hydrogen peroxide) produced by LAB also enhance the shelf-life of beverages though their shelf-life remains limited (less than or equal to 3 or 5 days). Limited shelf-life of such beverages poses a challenge to producers.

African fermented cereal beverages have preventive and curative properties for many known diseases. Some researchers have indicated that useful bacteria in fermented foods assist the digestive system in food assimilation and production of B-vitamins in the beverages (Kohajdová and Karovičová 2007). The B-vitamins are important co-factors for certain metabolic reactions in the human body. The beverages have anti-inflammatory, anti-diarrheal, anti-bacterial, anti-tumor, anti-spasmodic, laxative, anti-malarial, anti-hemorrhoid, anti-oxidant properties (Nyanzi and Jooste 2012; Iqbal et al. 2014; Murevanhema and Jideani 2013). Increased acidity in beverages by LAB prevents proliferation of both spoilage and food poisoning bacteria (Aka et al. 2014; Oyedeji et al. 2013; Kohajdová & Karovičová 2007). Some LAB and moulds produce bacteriocins and antibiotics which kill pathogenic bacteria. (Nyanzi and Jooste 2012).

Are starter cultures needed for African fermented cereal beverages?

Spontaneous fermentation is the process used in making all African traditional fermented cereal beverages and the procedure of how to make such beverages has been handed down from one generation to another. Since starter cultures are not used such fermentation is uncontrolled and thus the quality and stability of the products are compromised (Aloys and Angeline 2009; Guyot 2012).

Investigations made have so far revealed that LAB and yeasts are the major groups of microbes in fermented cereal beverages (Aka et al. 2014; Guyot 2012; Mugula 2003c). While the presence of yeasts favours the growth of bacteria through provision of growth factors, multiplication of yeasts in the beverages is favored by the acidic environment induced by LAB (Kohajdová and Karovičová 2007; Mugula et al. 2003a, b). This is the main reason of their predominance in the beverages as the growth of other microbes is inhibited by the acid medium as well as the metabolites produced by the two groups of microorganisms. The metabolites produced by the LAB and yeasts impart flavor and taste to the beverages (Aka et al. 2014; Mugula et al. 2003c).

Successful use of various species of LAB and yeasts as pure starter cultures and co-cultures to produce traditional fermented cereal products have been reported by Aka et al. (2014). Some of the drinks in which the co-culture has been used are reported to be potential probiotic foods when hygienically produced. Such drinks are *pito* (Nigeria, Ghana) and opaque sorghum beer *tchoukoutou* (Benin, Togo). It has also been observed that production process of enturire; an alcoholic sorghum-and honey-based beverage produced in Uganda can be modified and shortened by using pure starter cultures instead of spontaneous fermentation (Mukisa et al. 2016). Based on the above studies; Africa needs to develop pure starter cultures which contain efficacious microbial strain that can lead to control and optimization of the fermentation process so that beverages produced are of high organoleptic quality and microbial stability. It is thus obvious that selection of an appropriate strain or strains for a particular fermented product is paramount as a first step in a fermentation process which is controllable, predictable and efficient (Navarrete-Bolaños 2012).

Quality and safety of African fermented cereal beverages

Use of cereals such as maize, millet and sorghum which contain antinutritional factors (phytates, tannins) impede the bioavailability of vitamins, proteins and minerals and may lead to anaemia, and nutritional diseases like malnutrition and stunted growth. The impairment of absorption of minerals such as Fe, Ca, Mg, Mo, Zn is due to complex formation with tannins and phytates (Kohajdová and Karovičová 2007). It has been reported that some African fermented cereal beverages like burukutu (Northen Nigeria), malwa (Uganda) and tchoukoutou (Benin, Togo) contain tannins and phytates (Anukam and Reid 2009; Nout 2009). Some studies have indicated that African fermented cereal beverages are prone to heavy metal (Pb, Hg, As, Cd) contamination from the environment (Aka et al. 2014); however, this is not always the case and may probably depend on the location where the production is done and possibility of exposure from contaminated soil or water in the area. In human, heavy metals cause food poisoning and other toxic effects; e.g. renal toxicity.

Most of African fermented cereal beverages are prepared at homes. Preparations in unhygienic environment make the beverages susceptible to contamination by microflora (Blandino et al. 2003). Contamination in beverages mainly caused by humans, utensils, raw materials, processing devices, environment, sewage, rodents, poor storage and handling conditions (Todorov and Holzapfel 2014). Reported pathogens contaminating the African cereal beverages include *Staphylococcus aureus, Aspergillus flavus, Aspergillus niger*, *Escherichia coli*, *Bacillus* spp., *Proteus* spp., *Streptococcus* spp., *Rhizopus stolonifer* (Aka et al. 2014).

Beverages as delivery vehicles for probiotics

Literature indicates several beverage foods which are employed/potential as probiotics carriers. These include dairy products particularly yoghurts, fermented cereal beverages, fruit juice and liquid dietary supplements (Enujiugha and Badejo 2017; Mukisa 2016; Bansal et al. 2015). For the sake of this review; this section describes cereals (fermented cereal beverages) as the emerging probiotics carriers particularly for African countries.

Fermented cereal-based probiotic beverages (alternative vehicles for probiotics delivery)

Fermentation of cereals has been used as a food processing and preservation technology by most African communities since the dawn of human civilization; thousands of centuries ago (Mokoena et al. 2016; Guyot 2012). It is simple, inexpensive and of economic importance for Africa. It has been used to improve the nutritional value, organoleptic properties, safety, shelf life, digestibility and acceptability of traditional foods (Mokoena et al. 2016; Kumari et al. 2015; Mugula et al. 2003c). LAB are the main agents in the fermentation of African foods and beverages and are popularly referred to as “generally regarded as safe (GRAS)” (Mokoena et al. 2016; Kalui et al. 2010; Mugula et al.2003c). An updated list by 2012 of microbial species utilized in food fermentations is given by Bourdichon et al. (2012).

Research in functional foods like cereal based probiotic beverages is driven by consumers desire for quality life, healthcare cost reduction and the preference for foods which are naturally preserving and health improving (Kalui et al. 2010; Anukam and Reid 2009). African fermented cereal beverages with potential probiotics have health benefits related to probiotics (Kalui et al. 2010; Arslan and Erbas 2015). Development of fermented cereal based probiotic beverages from traditional African fermented cereal beverages will provide accessible, low cost and acceptable probiotic products especially to rural people. Consequently, millions of Africans will derive health benefits from the health-giving microorganisms. The WHO in 1994 indicated that probiotics are going to be the immune defense system of choice after ever increasing antibiotic resistance of existing antibiotic drugs (Kalui et al. 2010).

The negative effects of dairy products on consumers and the need for alternative sources of probiotics carriers to meet food preferences and demands of certain segments of the consumer market, have led to more researches around the world on various food matrices like fruit juices, vegetables and cereals (Bansal et al. 2015; Nyanzi and Jooste 2012; Gupta and Bajaj 2016). Fermented cereal-based probiotic beverages are fermented probiotic beverages with cereals used as probiotic carriers (Enujiugha and Badejo 2017; Arslan and Erbas 2015). So far much less work has been done to put in the consumer market fermented cereal-based probiotic beverages compared to probiotic milk or milk products (Angelov et al. 2006). Cereals make up the larger portion of staple diet for majority of people in Africa and other developing countries and thus there is justification for more researches on the use of spontaneously fermented cereal beverages as probiotics carriers. Moreover, it is known that 60% of the diet in developing countries is prepared from fermented cereals (Waters et al. 2015).

A handful of studies have been done on the possibility of using African traditional fermented cereal beverages as probiotics carriers (Kalui et al. 2010; Angelov et al. 2006). In one study, fermented rice or millet probiotic beverage were made using *Streptococcus thermophilus, Lactobacillus acidophilus* and *Bifidobacterium BB-12*; collectively referred to as ABT-2 starter culture and fortified with 10% each of sesame and pumpkin milk. Honey (5%) was also added before inoculation (Hassan et al. 2012). At the end of the 16 h fermentation time; the viable cell count was about 4.3×10^9 cfu ml^{-1}. Fortification changed acidity and probiotic bacteria counts. However, during storage of the beverages at + 4 °C; slight changes in the viable counts, acidity and pH were observed. Organoleptic characteristics were improved. The shelf life of the two beverages was estimated to be 15 days at + 4 °C during which the pH and acidity of each beverage remained above 4 and lower than 1%. Within the shelf life period, the probiotic bacterial count of the ABT-2 starter culture stayed at 8 log cfu ml^{-1}.

Traditional African fermented millet-based beverages with probiotic potential because of some probiotics they contain include Koko (West Africa), Mangisi (Zimbabwe and Uganda), Uji (East Africa), Burukutu and pito (Togo, Benin), Kunun-zaki (Nigeria, Niger, Tchad), Ogi (West Africa), Ben-saalga (Burkina Faso), Togwa (Tanzania) (Amadou 2011; Franz et al. 2014; Enujiugha and Badejo 2017). On the other hand, some traditional fermented cereal beverages are produced from sorghum malt. In one study, mixed starter cultures of LAB and yeasts used in the production of obushera; a traditional sorghum malt fermented beverage showed that in addition to producing lactic acid during fermentation, LAB produce flavor compounds as well (Mukisa et al. 2017). The flavor compounds include diacetyl, acetate, ethanol, acetaldehyde, acetone and acetoin. The key flavor compounds added by yeasts are acetaldehyde, methyl aldehydes, ethanol and methyl alcohol (Mukisa et al. 2017). Obushera produced was potentially probiotic as it contained probiotic microorganisms. Other studies with positive results on development of fermented cereal-based probiotic beverages include those by Ogunremi et al. (2015), Salmerón et al. (2015), and Di Stefano et al. (2017).

Benefits of the cereal-based probiotic beverages

They are considered as alternative delivery vehicles to cater for those people in Africa and elsewhere who cannot consume milk or milk products because of religious beliefs, cultural food taboos, high cholesterol content, allergenic to milk and being vegetarian or vegan (Nyanzi and Jooste 2012; Gupta and Bajaj 2016). They provide health benefits to majority of people especially rural people through cheaper probiotics from cheaper sources of food. Fermentation of cereals reduces/removes antinutritional factors and mycotoxins from them and thus provides essential minerals and vitamins to beverage consumers (Nyamete et al. 2016; Nyanzi and Jooste 2012). The probiotics they contain produce metabolites such as organic acids and bacteriocins which act as biopreservatives for the beverages. Since the cereals used for production of the fermented cereal-based probiotic beverages are customarily staple foods in Africa; they can easily be sourced. Of great importance is the fact that heavy dependency on milk and milk products as probiotic carriers will be greatly minimized and this will lead to increased availability and sustainability of cereal-based foods. The only challenge to the multitude of the benefits above is the fact that fermented cereal-based probiotic beverages are strain specific and thus careful screening and testing need to be done to obtain a specific, efficacious and safe probiotic strain for a given cereal substrate. Table 3 summarizes benefits of probiotic cereal-based beverages as compared to diary based probiotic products.

Food matrices, quality and functionality of cereal-based probiotic beverages

Scarce knowledge is available regarding the effect of food matrix and product formulation on probiotic functionality. Probiotic culture functionality; survival, physiology and efficacy may be affected by type of food format (Vijaya Kumar et al. 2015). Preparation of a functional probiotic food requires selection of a suitable food carrier and maintenance of viability and sensory characteristics which play a key role in making the product succeed in the market (Dey 2018; Rivera-Espinoza et al. 2010; Vijaya Kumar et al. 2015). Viability of probiotic cells during production of probiotic beverages is greatly reduced by technological conditions such as heat, mechanical damage and cell injury due to osmotic stress (Vijaya Kumar et al. 2015; Dey 2018).

The probiotic quality and functionality of the fermented cereal-based beverage lies in its ability to have viable probiotic bacteria in the range from 10^6 to 10^7 cfu/g and promote human health at the target organ/site (Enujiugha and Badejo 2017; Nyanzi and Jooste 2012; Hassan et al. 2012). Thus, when probiotic cultures are ingested; they should survive in sufficient numbers when transiting through the gastrointestinal tract in order to elicit their effects at target sites (Enujiugha and Badejo 2017; Panghal et al. 2018; Rivera-Espinoza et al. 2010). Some of the recent techniques used to improve the survival of probiotic strains during food processing and when ingested by human include encapsulation in prebiotics, genetic technique as well as a traditional way of increasing the inoculum size to pre-determined higher levels of bacteria (Enujiugha and Badejo 2017; Dey 2018). Some researchers have suggested that in vitro or in vivo survival of probiotics is highly influenced by the food carrier (Kalui et al. 2010).

The survival of probiotics during processing and long term storage heavily relies on the type of food matrix, rate of moisture content and cell condition (Vijaya Kumar et al. 2015). LAB grow well in cereals and this shows that probiotic fermented beverage with definite and consistent properties can be made using a human-derived probiotic strain in a cereal substrate under controlled conditions (Charalampopoulos et al. 2002). However, to produce such a product several considerations have to be made. These include composition and processing of the cereal grains,

Table 3 Probiotic fermented cereal beverages as compared to diary-based probiotics

Probiotic fermented cereal beverages	Diary based probiotics	References
Product with more nutrients; e.g. vitamin Bs (B1, B2, B3, B5, B6, B9 and B12), fibre especially indigestible fructo- and galacto-oligosaccharides which are used as prebiotics in the gut, digested carbohydrates (CHOs); i.e. utilizable di and monosaccharides, proteins and minerals (Fe, Zn, Mg, Ca, Mn, Mo) that are released by enzymatic degradation of cereals by LAB	Nutrients available, not as much as cereal based (e.g. lack of fiber, lack Fe, Zn, Mn, Mo, lack some B vitamins (B1, B2, B3, B5, B9 etc.)	Blandino et al. (2003) Zlatica Kohajdová and Karovičová (2007) Enujiugha and Badejo (2017)
Consumed by people of all age groups and health status as they are free of disorders caused by milk and milk products	Vegetarians, vegans, lactose intolerant and allergic people, people with milk taboo, some believers, hypercholesterolemic can't consume the products	Nyanzi and Jooste (2012) Vasudha and Mishra (2013) Aka et al. (2014)
Low production cost as the cereals are staple food locally available and beverages produced at household level or small-scale enterprises	High production cost as milk production involves a lot of processes e.g. raising dairy cattle, milking, sterilization, homogenization, cooling, packaging, cold chain maintenance	Franz et al. (2014)
Easily acceptable by local Africans as they make use of staple foods; maize, millet, sorghum to which they are accustomed	Milk and milk products may not be a local solution to nutrition and health maintenance as they are not part of the daily diet and can be too expensive for rural people in Africa	Kalui et al. (2010) Franz et al. (2014)
Fermented substrates (cereals) are ubiquitous in the world (73% of cultivated area) and provide more than 60% of the world food production	Milk is not available in all African communities; milk fermentation is mainly practiced in Northern West Africa, Northern Africa, the Sahara, the Savannah and hills and hill foots of East Africa	Kohajdová and Karovičová (2007), Todorov and Holzapfel (2014) Franz et al. (2014)
Several alternative probiotic carriers are available (maize, millet, sorghum, oats, barley)	Dependency on milk and milk products as the only probiotic carriers	Enujiugha and Badejo (2017)
Probiotic strains are specific to a given substrate based on presence of necessary growth factors such as Carbon source, nucleic acids, vitamin B-group, amino acids and minerals	Many probiotics grow on diary media as they have nearly all necessary growth factors	Nyanzi and Jooste (2012) McFarland (2015) Aka et al. (2014)
Prevent and cure known and life style diseases e.g. diarrhea, Cardiovascular disorders, allergy, lactose intolerance, hypercholesterolemia, constipation, urogenital tract infection, high blood pressure, cancer	Prevent and cure known and life style diseases e.g. diarrhea, Cardiovascular disorders, allergy, lactose intolerance, hypercholesterolemia, constipation, urogenital tract infection, high blood pressure, cancer	Kechagia et al. (2013) Hassan et al. (2012)

starter culture growth ability and productivity, probiotics stability during storage, sensory properties, and nutritional value of the end product (Charalampopoulos et al. 2002; Dey 2018). The ability to survive the acidic conditions of the ultimate fermented product and the harsh conditions of the GIT form a main factor in the selection of requisite probiotic bacteria. Furthermore, physical and chemical properties of the delivery media (food); e.g. buffering capacity and pH affect the survival of the probiotic bacteria during transit across the GIT (Charalampopoulos et al. 2002; Kalui et al. 2010).

The ability of probiotics to survive during preparation and storage of probiotic product is a main factor in producing such foods. Microbial growth and survival is essentially determined by ability to adapt to changing environments (Enujiugha and Badejo 2017; Kumari et al. 2015). It is a requirement that a probiotic has to show high survival rates in downstream processes, in food products during storage, in the upper GIT, at the site of action as well as high activity in the gut environment (Kumari et al. 2015). Storage of cereal products (beverages) at room temperature may affect their probiotic stability (Enujiugha and Badejo 2017). Encapsulation technology can be used to guarantee viability and stability of probiotic cultures (Charalampopoulos et al. 2002).

It is important to perform viable counts for stored fermented probiotic foods on economic, technological and efficacious reasons. The quality of the probiotic products is enhanced by the packaging material used and the storage conditions under which they are reserved (Kumari et al. 2015). In the probiotic product; the probiotic culture has to contribute to good sensory characteristics of the product. In order to have fermented cereal product with desired organoleptic properties; selection of an appropriate strain is mandatory in order to achieve distribution of the requisite metabolic end products (Charalampopoulos et al. 2002;

Kumari et al. 2015). As such it is normal to use a co-culture of probiotic bacteria in order to achieve fermentation of a particular product (Enujiugha and Badejo 2017; Kumari et al. 2015). Understanding the biochemical pathways for production of specific flavours assists in choosing the right starter. End product distribution of lactic acid fermentation is also determined by substrate composition and environmental conditions (e.g. temperature, pH) (Charalampopoulos et al. 2002; Kohajdová and Karovičová 2007).

Not all fermentative *Lactobacillus* spp. identified in African cereal-based beverages are probiotic, but the greater part of the microbes exhibit probiotic qualities (Navarrete-Bolaños 2012). *Lactobacillus acidophilus* is the LAB species which predominates in the intestinal tract of healthy humans and most often probiotic products contain this microbe (Enujiugha and Badejo 2017; Marsh et al. 2014). However, probiotic organisms are invariably not suitable as starter culture because of the difference in the environment within the GIT and that in the food matrix. To overcome this problem, as stated above, a co-culture is added to a probiotic preparation (Enujiugha & Badejo 2017; Hassan et al. 2012). While preparing fermented product having probiotics; it is recommended to carry out the fermentation at a temperature range of 37 °C–40 °C since most probiotic strains increase exponentially in that temperature range (Marshall and Mejia 2012).

Generally, African traditional fermented beverages are considered synbiotics because they contain both indigestible polysaccharides as well as the LAB which ferment the substrate (Mokoena et al. 2016; Lamsal and Faubion 2009). Though Africa has a rich diversity of fermented beverages; their utilization as potential sources of novel probiotics is still a challenge to African researchers and producers (Mokoena et al. 2016; Nyanzi and Jooste 2012). As such there is a need to increase research capabilities on how best to isolate, identify, and screen potential probiotics which are safe and efficacious from local beverages for use in fermented cereal-based probiotic beverages.

Importance of probiotic cereal-based beverages for Africa

Probiotics consumption have numerous benefits to human health such as boosting lactose tolerance, prevent constipation, prevention of allergies, improve balance of intestinal microflora, reduction of intestinal pH, reduction of cholesterol and risk of colorectal cancer, prevention and treatment of acute diarrhea and urogenital tract infections, inhibition of the helicobacter pyroli infection, modulation of the immune response, replenishing of intestinal microflora after treating certain diseases, release of B-group vitamins, decrease ammonia and other toxic substances and enhance functioning of the intestines (Enujiugha and Badejo 2017; Kechagia et al. 2013; Charalampopoulos et al. 2002; Vasudha and Mishra 2013). Furthermore, treatment with probiotics shorten the duration of infections as well as slows down susceptibility of host to pathogens (Vijaya Kumar et al. 2015).

In 2010 FAO estimates show that 925 million people; especially in rural areas suffered from hunger worldwide (Franz et al. 2014). However the majority of them were in sub-Saharan Africa which is the region inhabited with chronically malnourished people in the world (Franz et al. 2014; FAO 2015). In this region, young children have been chronically malnourished. This tendency has become a persistent problem (FAO 2015). The child mortality estimation report by the UN IGME in 2013 indicates that sub-Saharan Africa has the highest rates of under-five child mortality; i.e. 98 deaths per 1000 live births (You et al. 2013). Some studies estimate that an African child has a 10% chance of suffering from diarrhea on any given day and a 14% chance of dying from a severe episode (Franz et al. 2014; Sahlin 1999). In low-income countries; diarrhea is a key inducer of morbidity and mortality of millions of children (Kalui et al. 2010; Willumsen et al. 1997). In sub-Saharan Africa 37% of childhood deaths is attributed to diarrhea. Such deaths could be cut down by using fermented probiotic foods like fermented cereal-based probiotic beverages (when their potentiality as probiotic carriers is fully put into use) to improve the health of the children (Franz et al. 2014; Anukam and Reid 2009). Evidence exists which shows that some probiotic strains are efficacious in preventing and treating acute diarrhea (Kalui et al. 2010; Aka et al. 2014). One study has indicated that consumption of fermented maize gruel is able to mitigate prevalence of feacal enteric bacteria (*Shigella, Salmonella, E. coli*) in young children (Kalui et al. 2010). Fermentation; a process used in making cereal-based beverages breaks down and detoxifies the cereal raw materials thus raising the uptake of macro- and micro-nutrients as such reducing malnutrition in Africa (Franz et al. 2014; Nyamete 2016; Nyanzi and Jooste 2012).

Challenges and future prospects for cereal-based probiotic beverages in Africa

The major challenge for development and use of fermented cereal-based probiotic beverages for African populations including the food processors is the widespread ignorance regarding the health and nutritional benefits of probiotic foods/beverages. Inadequate knowledge on probiotics and their benefits makes the consumers skeptical on use of products containing them. Furthermore, the information available to African researchers on traditional fermented food matrices as carriers for probiotic microorganisms is still much less in comparison with dairy matrices. Cereals are complex substrates and as probiotic substrate perform differently among various probiotic species. However, lack of a systematic approach to identify both the intrinsic and processing factors that improve the growth and survival of the probiotic strain in vitro and in vivo in such matrices still pose a challenge to African researchers.

Another issue of concern for having quality and functional cereal-based probiotic beverages in Africa is the lack of appropriate facilities for production of probiotic starter cultures. It is a naked truth that most of the African fermented cereal beverages are produced through spontaneous fermentation which gives rise to beverages of varying qualities in terms of organoleptic and functional qualities. Consequently, there is a need of having sufficient cultures for controlled fermentations to improve the quality of the beverage products.

The prospects of having cereal-based probiotic beverages come out of a few studies which have revealed that traditional fermented cereal-based beverages are the potential source of microorganisms which exhibit probiotic characteristics and these should be harnessed to formulate fermented cereal-based probiotic beverages with beneficial health effects to human being.

Development of cereal-based probiotic beverages to help the African populations benefit from the nutrients found in fermented cereals, as well as the disease prevention and curative properties of probiotic cereal beverages lies on intensification of the search for novel probiotics from African fermented beverages; as most of the probiotic microbial cultures currently available in the market and in literature have been identified outside Africa. Once the novel probiotics from local beverages are obtained, they can be used to produce the cereal probiotic beverages that can be easily accessed by most Africans particularly those in rural areas where a big percentage carry on their livelihoods. Thus, easily sourced raw materials, cheaply prepared products, and economical price will make majority of people in Africa avail the benefits given by locally sourced probiotics and thus live health and prolonged lives.

Sourcing of novel probiotics is not a standalone prospect but this should be done concurrently with development of stress-tolerant starters with proven probiotic attributes through use of both conventional microbiological and novel molecular biology techniques such that probiotic qualities of the cereal beverages at the point of consumption, through the GIT, up to the site of action in the colon are appropriately maintained. Consequently, there is a need of making pure starter cultures of highly efficacious microbial strain in order to control and optimize the fermentation process and produce beverages of high organoleptic quality and microbial stability.

The ability of LAB to grow and ferment cereals and exist in high viable cell counts in such substrates provides avenues for developing novel fermented cereal-based beverages which are different from those locally consumed in various African countries. Furthermore, the functionality of LAB as cereal fermenters and synthesizer of oligosaccharides provides a chance for innovation of cereal-based probiotic beverages to compete with dairy versions in the consumer market.

Of great importance is the need to assess the performance of each probiotic species found in the African traditional fermented cereal beverages as this will help in selection of the best strains for use as probiotic starter cultures. This aspect is critical as it underscores the fact that a competitive advantage of cereal-based beverages in the world market can only be achieved through improvement of technology and functional properties of the probiotics, in addition to the viability of probiotics used in such products.

Conclusion

In African countries and other developing countries; cereals occupy a larger share of the staple diets and this forms the basis for introducing probiotics in such foods particularly cereal beverages which are consumed regularly in social gatherings and other important community rituals. Such beverages in turn can provide health benefits including prevention and curing of diseases. Though traditional African fermented cereal beverages have proven probiotic potential; some research gaps have to be filled in. These include isolation of novel probiotics and development of stress-tolerant starters with proven probiotic attributes from the beverages; that are able to maintain their probiotic qualities and functionality while transiting the GIT to the target site in the colon.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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