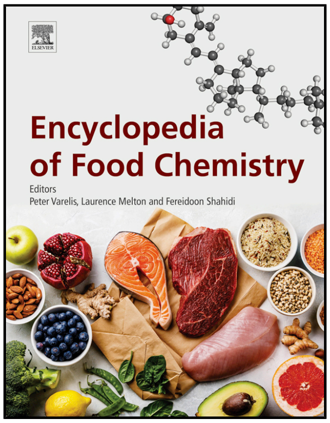

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Health-Promoting Fermented Foods

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Introduction: Overview of Fermented Foods

Fermentation of food substrates is an ancient practice, often described as a cheap, energy efficient, low-technology, and one of the oldest forms of traditional food processing and preservation techniques, usually carried out to introduce a variety of diets into food preparations (Ferri et al., 2016; Guyot, 2012; Kebede et al., 2007; Simango, 1997). Most food materials are highly perishable in their raw states (e.g. milk, cassava, fruits and vegetables, edible bamboo shoots etc.), which make them prone to spoilage attack, and in some cases, inedible and surplus after harvesting. Hence, they are fermented by natural inoculation and biochemical activities of microorganisms, which help to achieve post-harvest preservation, prevent physiological deterioration and losses, make inedible ones edible, with improved shelf-life, food safety, as well as ensuring availability of foods all year round (Patra et al., 2016; Rolle and Satin, 2002). Generally, these microorganisms are mostly from the raw food materials, fermentation vessels and utensils, processors, contaminants and other environmental microflora, selected to actively dominate and ferment the substrates through competitive adaptation and direct competition for available nutrients (Franz et al., 2014; Tamang, 1998).

A diversity of fermented foods and beverages obtained from food substrates, such as cereal grains, legumes and pulses, roots and tubers, fruits, vegetable leaves and edible bamboo shoots, milk and dairy products, meat and seafoods, miscellaneous food commodities (e.g. tea leaves, cocoa, sugar cane juice, oil palm sap etc.) is abundantly available in different parts of the world (Tamang et al., 2016a). Divergent microbial strains of bacteria (*Bacillus*, lactic acid bacteria, *Acetobacter*, Micrococcaceae), yeasts and mycelia or filamentous moulds have been reported to be principally responsible for the biotransformation of these food materials, resulting in the production of either acidic, alcoholic or alkaline-fermented food products (Steinkraus, 1997; Tamang, 1998). During the process of fermentation, microorganisms become exposed to food substrates, which leads to utilization of the nutrient contents. The nutrients and organic chemical compounds are used as carbon, nitrogen, electron and energy sources, through various enzymatic and biochemical reactions, which bring about desirable functional changes along with the production of metabolites that impart functional benefits. Beneficially, microbial fermentation enhances nutrient enrichment and bioavailability, development of attractive flavour, taste, aroma and texture, in addition to improved digestibility of carbohydrates and proteins, as well as bio-preservative effects (Blandino et al., 2003; Nout, 2009; van Boekel et al., 2010). Apart from the production of pleasant and acceptable quality food substances preferred by consumers (compared to their respective raw food materials), food fermentation also supports prolonged shelf-life of final food products (Caplice and Fitzgerald, 1999; Holzapfel, 1997). Other benefits include detoxification and reduction in undesirable toxic components and anti-nutritional factors, food fortification with essential amino acids and fatty acids, vitamins, minerals and antioxidants, stimulation of health promoting functions, value-added advantage and new products development (Oboh, 2006; Ouoba et al., 2003; Teniola and Odunfa, 2001).

Among these advantages, the consumption of fermented foods and beverages for their health-promoting properties, especially in disease prevention and improvement of human health has long been recognized by consumers. This is in consonant with early comments by the Russian Scientist, Élie Metchnikoff who suggested that the prolonged life span of the Bulgarian peasants resulted from the consumption of fermented dairy foods, such as yoghurt, sour milk and *kefir*, which contain lactic acid bacteria (LAB) (Metchnikoff, 1907). Metchnikoff's observation has since then stirred up consumers' consciousness and awareness in the consumption of foods with health-promoting values, beyond the purpose of nutrition and other basic benefits. Thus, food fermentation has received increasing research interests and attention, especially in food science, human nutrition and applied microbiology (Saarela et al., 2002; Salmerón, 2017). Multiple studies and evidence-based investigations have shown that fermented foods carrying both large populations of live microbial cultures and their metabolites, or either of these, may impart health beneficial functions (Barla et al., 2016; Kim et al., 2016; Singh et al., 2014; Tamang et al., 2016b). Hence, the scope of this chapter provides a comprehensive account and current information on health-promoting fermented foods and beverages around the world. Such benefits include reduction in serum and blood cholesterol, production of exopolysaccharides (EPSs) and bioactive compounds, production of antimicrobial compounds against potential pathogenic microorganisms, anti-mutagenic, anti-carcinogenic, anti-tumour effects and fibrinolytic activities. Other health effects include amelioration of metabolic and physiological disorders, improvement in cognitive brain functioning, enhanced probiotic properties, etc. In addition, highlights of the different types of fermented foods, and the predominant microorganisms associated with them will be discussed.

Diversity of Fermented Foods and Beverages Around the World

Fermented foods and beverages are classified on the basis of raw food materials used in producing them, whether alkaline, acidic, alcoholic, or both acidic and alcoholic as well as the predominant group of microorganisms (**Table 1**).

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Table 1 Some selected fermented foods and beverages around the world, based on divergent raw food substrates

Products	*Food substrates*	*Nature*	*Predominant microorganisms*	*Country of origin*
mawè	maize	acidic dough	*Lactobacillus fermentum*, *Saccharomyces cerevisiae*	Benin Republic
tchoukoutou	sorghum	alcoholic opaque beer	*Sac. cerevisiae*, *Candida krusei*, *Lac. fermentum*	Benin Republic
dosa	rice and black gram	acidic and slightly alcoholic batter	*Leuconostoc mesenteroides*, *Lac. fermentum*, *Bacillus amyloliquefaciens*, *Sac. cerevisiae*, *Debaryomyces hansenii*	India, Sri Lanka, Malaysia, Singapore
pozol	maize	mildly acidic dough	*Lac. fermentum*, *Lac. plantarum*, *Lac. casei*	Mexico
sourdough	rye, wheat	mildly acidic, leavened bread	*Lac. sanfranciscensis*, *Lac. alimentarius*, *Lac. buchneri*	United States of America, Europe, Australia
iru	African locust bean	alkaline condiment	*Bac. subtilis*, *Bac. amyloliquefaciens*, *Bac. cereus*	Nigeria
kinema	soybean	alkaline condiment	*Bac. subtilis*, *Bac. licheniformis*, *Bac. cereus*	India
natto	soybean	alkaline condiment	*Bac. subtilis* (*natto*)	Japan
fufu	cassava	acidic dough	*Lac. plantarum*, *Lac. cellobiosus*, *Bacillus* species	West Africa
tarubá	cassava	acidic beverage	*Lac. plantarum*, *Lac. brevis*, *Leu. mesenteroides*, *Pichia exigua*, *Can. tropicalis*	Brazil
sauerkraut	cabbage	acidic, sour salad	*Leu. mesenteroides*, *Pediococcus pentosaceus*, *Lac. plantarum*, *Lac. brevis*	Europe, Canada, United States of America, Australia
table olives	olive	acidic, side dish salad	*Lac. plantarum*, *Lac. pentosus*, *Leu. mesenteroides*, *Ped. pentosaceus*,	United States of America, Spain, Portugal, Peru, Chile
kimchi	cabbage, green onion, hot pepper	acidic, mildly sour, side dish	*Leu. mesenteroides*, *Leu. citreum*, *Leu. kimchi*, *Lac. plantarum*, *Weissella cibaria*	Korea
kefir	milk	acidic, mildly alcoholic fermented milk	*Lac. kefiranofaciens Lac. brevis*, *Streptococcus thermophilus*, *Lac. plantarum*, *Lac. casei*, *Can. kefyr*, *Sac. cerevisiae*	Russia, Europe, Middle East, North Africa
dahi	milk	acidic viscous curd	*Lac. alimentarius*, *Lac. paracasei*, *Lac. acidophilus*, *Lac. helveticus*	India, Nepal, Sri Lanka, Bangladesh, Pakistan
amasi	milk	acidic, sour, with thick consistency	*Lactococcus lactis* subsp. *lactis*, *Lac. lactis* subsp. *cremoris*, *Leuconostoc* spp.	South Africa, Zimbabwe
alheira	pork or beef	dry/semi-dry sausage	*Lac. plantarum*, *Lac. paraplantarum*, *Lac. brevis*, *Lac. sakei*	Portugal
ngari	fish	mildly acidic fermented fish	*Lac. plantarum*, *Lac. pobuzihii*, *Lac. coryniformis*, *Bac. subtilis Staphylococcus carnosus*	India
tej	honey	sweet, effervescent and cloudy alcoholic	*Sac. cerevisiae*, *Deb. phaffi*, *Kluyveromyces bulgaricus*	Ethiopia
kombucha	tea	fermented tea drink	*Sac. cerevisiae*, *Acetobacter aceti*, *Gluconobacter oxydans*	China, India

Adapted and modified from Tamang et al. (2016a).

Cereal Fermented Foods

Non-alcoholic fermented cereal foods produced from maize (*Zea mays* L.) in Africa include *doklu* (Côte d'Ivoire), *kenkey* (Ghana), *amahewu* (or *mahewu*) and *incwancwa* (South Africa), *mawè* (Benin Republic), *ogi* (Nigeria), *poto–poto* (Congo), *togwa* (Tanzania), *ikii* and *uji* (Kenya), *munkoyo* and *chibwantu* (Zambia), as well as *tobwa*, *mutwiwa* and *ilambazi lokubilisa* (Zimbabwe). *Ben-saalga* and *dégué* (Burkina Faso), *koko* or *akasa*, *koko* sour water and *fura* (Ghana), and *kunun-zaki* (Nigeria) are made from pearl millets [*Pennisetum glaucum* (L.) R. Br.], while *mangisi* (Zimbabwe) is from finger millet (*Eleusine coracana* Gaertn.). Fermented sorghum [*Sorghum bicolor* (L.) Moench] foods include *obushera* (or *bushera*) (Uganda), *gowê* (Benin Republic), *hussuwa* and *kisra* (Sudan), *bogobe* (Botswana), *obiolor* and *ogi-baba* (Nigeria) (Assohoun-Djeni et al., 2016; Gadaga et al., 1999; Odunfa and Adeyele, 1985; Owusu-Kwarteng et al., 2012; Schoustra et al., 2013). Major fermented cereal alcoholic beverages are *pito*, *dolo*, *tchapalo*, *burukutu*, *tchoukoutou*, *busaa*, kaffir beer, *muramba*, *pombe*, *impeke*, *malwa*, *merissa*, *amgba*, *bouza*, *umbugug*, *doro*/*uthwala*, *tella* (Holzapfel, 1997; Jespersen, 2003). Fermented baked snacks and pancakes also produced from cereals include *injera*, *kisra* and *masa*. Common fermented cereal foods in Asia are *dosa* (pancake), *idli* (pudding), *hamei* and *xaj-pitha* (rice wines, India), *congee* and *suanzhou* (acidic gruel, China), *chhang* (barley beer, India), *jalebi*, *koozh* (Indian porridge), *adhirasam* (rice doughnut), *hopper* (steamed baked, Sri-Lanka), *puto* (Philippines), *sake* (also *saké*, Japanese rice wine) and *dhokla* (dough) (Jeyaram et al., 2008; Qin et al., 2016). Bread, sourdough bread, *San Francisco* bread, rye bread, beer, *boza* (Turkish sour drink), *bagni* (millet alcoholic drink, Russia), *hulumur* (sorghum beverage drink, Turkey), *kvass* (a non-alcoholic beverage similar to *boza*), *perkarnaya* (Russia), *pumpernickel* (Switzerland), and Mexican *pozol* and *atole agrio* comprise the various cereal fermented foods in Western and Eastern countries. Products such as *champus* and *chicha de jora* (both mild alcoholic beverages), and *masa agria* (maize dough) are found in South America (Chaves-Lopez et al., 2016; Elizaquível et al., 2015; Väkeväinen et al., 2018; Ventimiglia et al., 2015).

Fermented Legume Protein-Rich Seeds

Traditional fermented protein-rich, legume-based foods are widely consumed in many African and Asian countries. In East and Southeast Asia, soybean [*Glycine max* (L.) Merr.] seeds are fermented by *Bacillus subtilis* to produce varieties of alkaline fermented food condiments, such as Japanese *natto*, Indian *kinema*, *hawaijar*, *bekang*, *tungrymbai*, *peruyaan* and *aakhone*, Thailand *thua nao*, Korean *cheonggukjang*, and Chinese *douchi* and *yandou* (Sanjukta and Rai, 2016). The major biochemical change is protein hydrolysis due to high proteinase activity of *Bac. subtilis*, which results in rapid production of polypeptides, amino acids, ammonia, and polyglutamic acid (PGA) in addition to other volatile compounds that contribute to the product's characteristic pungent smell and ammoniacal flavour (Leejeerajumnean et al., 2001; Odunfa, 1985). A similar food flavouring agent in Africa from soybean is *soy-daddawa*, but *iru* (also known as *daddawa*), *soumbala*, *afitin*, *nététou*, *kinda*, *oso*, *kawal*, *cabuk*, *bikalga*, *dawadawa botso*, *datou*, *mbuja*, *furundu*, *maari* and *tayohounta* are produced using non-soybean seeds, while cassava leaves form the raw material for the production of *ntoba mbodi* (Adewumi et al., 2014; Parkouda et al., 2009; Vouidibio Mbozo et al., 2017). Other fermented soybean foods in Asia where filamentous and mycelia moulds like *Aspergillus oryzae*, *Rhizopus oligosporus*, *Rhi. oryzae*, *Rhi. microsporus*, *Mucor sufu*, *Muc. wutungkiao*, *Muc. plumbens*, *Actinomucor taiwanensis*, *Act. elegans* and *Absidia corymbifera* dominate the fermentation process or with the participation of *Bacillus* species, include Indonesian *tempe*, Chinese *sufu* (also *fu-ru* or *tofu*) and *soy sauce*, Korean *meju*, *doenjang*, *ganjang* (a soy sauce), *doenjang-meju* and *gochujang*, Japanese *miso* and *shoyu* (Han et al., 2001; Jung et al., 2014; Nout and Kiers, 2005).

Fermented Starchy Roots and Tuber Products

Cassava, yam, cocoyam and potatoes constitute starchy root and tuber crops that provide carbohydrate, an energy source in the diets of millions of people, especially in sub-Saharan (Cock, 1982; O'Hair, 1990). In Africa, cassava (*Manihot esculenta* Crantz) is the most abundant and importantly consumed root crop despite the presence of linamarin and lotaustralin, which are toxic cyanogenic glucosides (Aryee et al., 2006; Kimaryo et al., 2000). Processing by fermentation, involving *Lactobacillus plantarum*, *Lac. fermentum*, *Lac. pentosus*, *Lac. brevis*, *Leuconostoc mesenteroides* subsp. *mesenteroides*, *Weissella paramesenteroides*, *Wei. cibaria*, *Wei. confusa* and *Pediococcus pentosaceus*, primarily brings about detoxification and biochemical activities of the cassava tubers. This enhances acidification and imparts organoleptic properties, leading to the production of varieties of edible fermented food products, such as, *gari*, *agbelima*, *akyeke*, *attiéké*, *fufu*, *kivunde*, *lafun* (or *kokonte*), *chikwangue*, *cingwada*, *kocho*, *ikivunde*, *imikembe*, *inyange*, and *ubuswage*, among others (Adesulu-Dahunsi et al., 2017; Amoa-Awua et al., 1997; Kostinek et al., 2007; Obilie et al., 2004). Cassava fermentation for *gari* production is a solid-state natural inoculation, unlike *fufu*, *attiéké*, *lafun* and *agbelima* where submerged fermentation is employed (Coulin et al., 2006; Oyewole, 2001). Other microorganisms, including *Bacillus* species and yeasts have also been reported to partake in cassava fermentation. *Bac. subtilis* was found to produce amylases that were involved in the initial breakdown of cassava starch into simple sugars that are then fermented by LAB (Amoa-Awua and Jakobsen, 1995). *Saccharomyces cerevisiae*, *Pichia scutulata*, *Kluyveromyces marxianus*, *Hanseniaspora guilliermondii*, *Candida tropicalis*, *Can. glabrata* and *Can. krusei* are the yeasts species isolated during traditional *gari* and *lafun* production in West Africa (Oguntoyinbo, 2008; Wilfrid Padonou et al., 2009). Cassava is also processed by solid-state fermentation for the production of *tarubá*, an indigenous beverage by the Amerindian tribes in Brazil (Ramos et al., 2015).

Fermented Fruits and Vegetables

Lactic acid fermentation of fruit and vegetable foods is traditionally carried out in most parts of Europe, United Sates of America and Asian sub-continents for the purpose of preservation against spoilage and rotting. Other reasons include prevention of post-harvest losses, shelf-life extension, improvement in nutrient composition, detoxification and reductions in levels of anti-nutritional components (e.g. glucosinolates in cabbage and oleuropein in olive), in order to make them edible and available during the off season (Gail-Eller and Gierschner, 1984; Ross et al., 2002; Sánchez et al., 2000a). Fermentation processing of heads of white cabbage (*Brassica oleracea* var. *capitata* L.), cucumber (*Cucumis sativus* L.) and olive (*Olea europaea* L.) for the production of sauerkraut ('sour herb' or 'sour cabbage' as known in Germany), pickles and table olives respectively, is commonly practised in Western countries. However, Korean *kimchi* from Chinese cabbage (*Brassica rapa* subsp. *pekinensis*) is the most popular fermented vegetable side dish food in Asia (Oguntoyinbo et al., 2016a; Patra et al., 2016). Fermented vegetable ethnic foods that are also common in Asia are *gundruk*, *sinki*, *khalpi*, *sunki*, *pak-sian-dong*, *tursu*, *suan-tsai*, *salgam*, *kanji*, *jiang-gua*, *hardaliye*, *dhamuoi*, *dakguadong*, *goyang*, *phak-gard-dong* and *gherkins*, while the edible fermented bamboo shoots include *mesu*, *soidon*, *soibum*, *soijim*, *ekung*, *hirring*, *naw-mai-dong*, *inziangsang*, *doubanjiang* and *pao cai* (Altay et al., 2013; Anandharaj et al., 2015; Tamang et al., 2008; Tamang and Tamang, 2009). In Africa however, very few vegetable leaves like those from cowpea [*Vigna unguiculata* (L.) Walp.] and African kale [*Brassica carinata* A. Braun] are subjected to fermentation before consumption (Kasangi et al., 2010; Oguntoyinbo et al., 2016b). Spontaneous fermentation of fruits of capper berries (*Capparis spinosa* L.), sweet cherry (*Prunus avium* L.) and 'Almagro' egg plant (*Solanum melongena* var. *esculetum* L.) are equally found in the Mediterranean, where they form part of various cuisines (Perez Pulido et al., 2005; Sánchez et al., 2000b).

Fermented Milk and Dairy Products

Among other fermented food substrates is milk, which is highly perishable with a very short shelf-life because it contains major classes of nutrients. The high nutrient density makes milk a suitable medium for microbial contamination and colonization by autochthonous, spoilage and pathogenic microorganisms. For preservation and digestibility purposes, milk is naturally fermented at ambient temperature, or with starter cultures in the raw form or after pasteurization (Jans et al., 2017). Yoghurt is a fermented dairy food that is produced commercially from pasteurized milk using strains of *Lac. delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* starter cultures. While *Str. thermphilus* is responsible for the metabolism of lactose sugar to produce lactic acid, which enhances milk acidification, *Lac. delbrueckii* subsp. *bulgaricus* contributes to aroma and flavour production (Innocente et al., 2016). Cheese is another commercial fermented milk food, with different types depending on the origin of production, ripened or unripened, soft or hard. During cheese manufacturing, the acidic environment created by LAB, neutralizes the negative charge ion of the milk casein, for precipitation and coagulation, forming a gel cheese curd at isoelectric point of pH around 4.6. The major cheese microbiota includes *Lactococcus lactis* subsp. *lactis*, *Lac. lactis* subsp. *cremoris*, *Lac. lactis* subsp. *lactis* var. *diacetylactis*, *Leu. mesenteroides* subsp. *cremoris*, *Lac. helveticus*, *Lac. casei*, *Lac. plantarum*, *Lac. salivarius*, *Enterococcus faecium*, *Ent. durans*, *Propionibacterium freudenreichii*, *Debaryomyces hansenii*, *Yarrowia lipolytica*, *Kluveromyces marxianus*, *Geotrichum candidum*, *Penicillium roqueforti*, *Pen. camemberti*, *Pen. glaucum* and *Staphylococcus* species (Quigley et al., 2011).

Naturally fermented milk (NFM) products are likewise available in different parts of the world apart from cheese and yoghurt. Examples include *kefir* (fermented milk with *kefir* grain), *koumiss* (in Russia), *sethemi*, *amasi*/*wakakora*, *mukaka*, *hodzeko*, *mbanik*, *kule naoto*, *mursik*, *amabere*, *amaruranu*, *suusac*, *raib*, *zabady* (like plain yoghurt), *urubu*, *amateregua*, *amavuta*, *jben*, *leban*, *rob*, *gariss*, *fènè*, *mabisi*, *dhanaan*, *makamo*, *nunu*, *nyarmie*, *kindirmo*, *maishanu*, *arera* and *pendidam* (from different parts of Africa), *laban* (Lebanon), *doogh* (Iran), *aryan* (Turkey), and *kurut* (China) (Akabanda et al., 2013; Franz et al., 2014; Jans et al., 2017). Others are *långfil*, *filmjölk*, *viili*, *tettemelk*, *ymer* and *talouspiimä* in the Scandinavian, and *dahi* (yoghurt-like), *chhurpi*, *somar*, *chhu*, *khachu*, *philu*, *shrikhand*, *philu* and *shyow* in India (Duboc and Mollet, 2001; Ghatani and Tamang, 2017). Fermented curds similar to cottage cheese include *datsi*, *warankashi*/*woagashi*, *oscypek*, *batzos*, *rigouta*, *ergo*, *ititu*, *ayib*, while traditional fermented butters are *kibe*, *neterkibe*, *omashikwa*, *klila* and *chhash*.

Fermented Meat and Seafood Products

Meat and fish products are highly nutritious, and perhaps the richest source of protein foods, when compared to plants, because of their amino acid quantity and quality, which may be lacking in other protein sources (Lücke, 2000). Fresh cut meat and fish are susceptible to microbial contamination and spoilage because of their relatively high moisture contents and water activity (a_w) (Adams, 2010; Gram and Huss, 1996). They are usually processed by cooking, smoking, drying, canning and grilling before consumption. Fermentation of meat and seafood is also carried out, especially in Southern and Central Europe, United States of America, including Asia and some parts of Africa. Fermented sausage (also called 'salami' in Italy) is the most popular and the microbial ecology indicates the important presence and technological roles of two main groups of bacteria, LAB (*Lac. sakei*, *Lac. curvatus*, *Lac. paracasei*, *Lac. plantarum*, *Lac. pentosus*, *Lac. buchneri*, *Lac. brevis*, *Lac. rhamnosus*, *Lac. alimentarius*, *Lac. farciminis*, *Ped. pentosaceus*, *Ped. acidilactici*, *Leu. mesenteroides*, *Leu. pseudomesenteroides*, *Leu. carnosum*, *Leu. gelidum*), and Gram-positive coagulase-negative cocci (CNS: *Staphylococcus xylosus*, *Sta. carnosus* subsp. *carnosus*, *Sta. pasteuri*, *Sta. warneri*, *Sta. saprophyticus*, *Sta. epidermis*, *Sta. equorum*, *Sta. simulans*, *Sta. sciuri*, *Sta. succinus*, *Kocuria varians*) (Greppi et al., 2015; Rantsiou et al., 2005; Villani et al., 2007). *Can. famata*, *Deb. hansenii*, *Willopsis saturnus*, *Pen. nalgiovense*, *Pen. chrysogenum* and *Pen. camemberti* have also been found to be present. Other sausage-like fermented meat products are *alheira* in Portugal, *sucuk* in Turkey, *nham* in Thailand, *nem chua* in Vietnam, Taiwanese *ham*, *wakalim* in Ethiopia, *jamma*, *arjia* and *kargyong* in India (Albano et al., 2008; Bacha et al., 2010; Kesmen et al., 2012; La Anh, 2015; Oki et al., 2011; Tu et al., 2010).

Fermented fish are numerous and predominantly produced in South and Southeast Asian regions, with a few of them in Africa and some other parts of the world. They include salted fermented fish sauce (e.g. *budu*, *kecap ikan*/*bakasang*, *nam-pla*, *ngan pyaye*, *nuoc* *mam*, *patis*, *yu-lu*, *shottsuru*, *ishiru*, *jeotkuk*, *garos*), and fish pastes (*bagoong*, *belacan*, *hentak*, *jaadi*, *kapi*, *kung chao*, *mehiawah*, *ngapi*, *narezushi*, *pla ra*, *trassi*, *tungtap* (Jung et al., 2013; Thapa et al., 2004). Fermented fish foods that are neither sauce nor paste, with or without salt, and sometimes sun-dried include *jeotgal*, *hákarl*, *surstrØmming*, *rakØrret*, *fessiekh*, *ngari*, *pedah*, *balao balao*, *guedj*, *bonome*, *shiokara*, *pekasam*, *kung som* (Devi et al., 2015; Guan et al., 2011; Sanchart et al., 2017).

Alcoholic Drinks and Other Miscellaneous Fermented Foods

Non-cereal alcoholic beverages and miscellaneous fermented food products are available in various parts of the world, and are produced from different food raw materials. For example, wine made from grape juice/must, is consumed throughout the world, and fermentation occurs through a divergent community species and strains of yeasts, although predominantly by *Sac. cerevisiae* strains (Perrone et al., 2013). LAB, mostly *Oenococcus oeni*, is responsible for secondary or malolactic fermentation (MLF) that involves conversion/decarboxylation of dicarboxylic L-malic acid found in grape juice to monocarboxylic L-lactic acid (Liu, 2002; Osborne and Edwards, 2005). Technologically, *Oen. oeni* population in wines usually cause reductions in pH below 3.5, resulting in a softer-tasting wine; ensures microbial stability, and evolution of various sensory changes, due to production of a number of secondary metabolites (Dicks and Endo, 2009; Swiegers et al., 2005). *Oen. oeni* has been described as the preferred starter culture for MLF, whereas other wine-related LAB are known to cause spoilage in wine. This is because *Oen. oeni* has higher tolerance to wine conditions, such as $\text{pH} < 3.5$ and ethanol concentration $>10\%$ and is less prone to off-flavour production (Versari et al., 1999).

Traditional wines, beers and alcoholic drinks, prepared from carbohydrate-rich substrates and indigenous fruits are particularly popular in Africa, South America and some other parts of the world. These include palm wine from palm sap/juice, *tej* (honey wine in Ethiopia), *mbege*, *urwarwa* and *isongo* (banana beer in Tanzania and Burundi), *marula*, *murara*, *mutandavira*, *masau* and *mudetemwa* fruit wines and beer in Zimbabwe, *basi* and *cachaça* (fermented sugar cane juices), *kanji* and *aloja* (alcoholic beverages from carrot and carob beans respectively), *caxiri*, *pulque* etc (Aloys and Angeline, 2009; Escalante et al., 2008; Gadaga et al., 1999; Mulaw and Tesfaye, 2017; Nyanga et al., 2013; Santos et al., 2012). Apart from black tea that is popularly consumed around the world, traditional fermented tea products such as *miang*, *fuzhuan brick*, *puer* and *kombucha* are also found in Asia. Other miscellaneous fermented products are coffee and cocoa beans in chocolate manufacturing, *nata de coco* and *nata de piña*.

Health-Promoting Effects of Fermented Foods and Beverages

Production of Antimicrobial Compounds Against Pathogenic Microorganisms

In starchy food materials, LAB species typically secret α-amylase enzyme, which hydrolyzes complex carbohydrates into fermentable sugars such as glucose and maltose. Upon sugar metabolism, LAB produce lactic acid as the principal metabolite but bacteriocins, a group of antimicrobial proteins or peptide compounds that inhibit closely related bacterial genera and other unrelated microbial species are also released. The production of lactic acid causes pH reduction to below 4.2 in acidic fermented foods and beverages, facilitating the inhibition and/or elimination of the onset and growth of food spoilage microorganisms and food-borne pathogens, which are known causative agents of several food-borne diseases and human illnesses (Giraffa, 2004; Holzapfel, 1997). Lactic acid-fermented food products containing viable bacterial cultures and metabolites, and their potential health benefits in diseases control have been previously identified.

Odugbemi et al. (1991) demonstrated the effective control of enteropathogenic *Escherichia coli* (EPEC), *Salmonella typhi* and *Sal. paratyphii* in *ogi*, a lactic acid cereal gruel used for infant feeding in West Africa. Mbugua and Njenga (1992) reported the antimicrobial activities of LAB against diarrhoea-causing bacteria – *Sal. typhi*, EPEC and *Shigella dysenteriae* in *uji*. Other studies on *mahewu*, *kenkey*, *ikii*, *bushera* and *togwa*, revealed the inhibition of the proliferation of food-borne pathogens and disease-causing bacteria such as *Campylobacter jejuni*, *Shi. flexneri*, EPEC and coliforms (Kalui et al., 2009; Kingamkono et al., 1998; Mensah et al., 1988, 1991; Muyanja et al., 2003; Nout et al., 1989; Simango and Rukure, 1991). An optimized *ogi*, 'DogiK', prepared with lactobacilli strain starter cultures, was developed for the control of infantile diarrhoeal disease in Nigeria (Olukoya et al., 1994). In a related study, Adebolu et al. (2007) confirmed the anti-diarrhoeal potential of *ogi* liquor harbouring *Lactobacillus* species, with respect to *Shi. dysenteriae*, *Sal. typhimurium*, *Esc. coli*, *Sta. aureus* and *Enterobacter* spp. Bacteriocinogenic *Lac. plantarum* strains from *ben-saalga* was found to exhibit broad spectra antimicrobial properties against food-borne pathogenic strains of *Bac. cereus*, *Ent. faecalis*, *Listeria innocua*, *Lis. monocytogenes*, *Sta. aureus* and *Sal. enterica* (Omar et al., 2006). In like manner, bacteriocin-producing *Lac. plantarum*, *Ent. faecium* and *Leu. lactis* in *boza* demonstrated bactericidal effects regarding *Esc. coli*, *Klebsiella pneumoniae*, *Listeria* spp. *Pseudomonas aeruginosa* and *Staphylococcus* spp. (Todorov, 2010).

There are various reports on the health-promoting functions of LAB in fermented milk foods, fruits and vegetables. Yoghurt and acidophilus-fermented milk containing *Lac. acidophilus* were effectively used in the treatment of gastrointestinal tract (GIT) disorders, including colitis, diarrhoea and constipation (Sanders, 1993). Olasupo et al. (1999), Ghrairi et al. (2004) and Mitra et al. (2010) isolated a nisin Z *Lac. lactis* strain from *wara* (short form of *warakanshi*), *rigouta* and *dahi* respectively, which possessed anti-listerial characteristics, by inhibiting *Lis. innocua*, *Lis. monocytogenes*, as well as *Clostridium butyricum*, *Clo. perfringens*, *Bac. cereus* and *Sta. aureus*. Another *Lac. lactis* strain from goat cheese whey in Brazil likewise showed anti-listerial properties (Chaves de Lima et al., 2017). LAB present in Iranian, Turkish and Algerian fermented dairy foods produced bacteriocin and bacteriocin-like inhibitory substances (BLIS) against *Lis. monocytogenes*, *Lis. innocua*, *Sal. enteritidis*, *Sta. aureus*, *Ent. faecalis*, *Bac. cereus*, *Sta. epidermidis*, *Esc.*

coli and *Yersinia enterocolitica* (Aslim et al., 2005; Iranmanesh et al., 2014; Mezaini and Bouras, 2013). Bacteriocin-producing LAB screened from *kurut*, a Chinese traditional fermented *yak* milk was antagonistic towards *Sta. aureus* and *Esc. aerogenes* (Luo et al., 2011). *Lac. lactis* subsp. *lactis* biovar. *diacetylactis* strain was used alone as starter culture or in combination with *Can. kefyr*, to produce traditional fermented milk in Zimbabwe; this retarded the growth and survival of *Esc. coli* and *Sal. enteritidis* strains originating from human clinical samples (Mufandaedza et al., 2006). Similarly, *Lac. lactis* subsp. *lactis* bacteriocin was applied *in situ* for the biological control of *Lis. monocytogenes* in *jben* (Benkerroum et al., 2000). A crude extract containing antimicrobial peptide of milk fermented with *Lac. plantarum* 26, displayed antagonistic characteristic towards food-borne pathogens, particularly *Lis. innocua* (Aguilar-Toalá et al., 2017). Pediocin, a bacteriocin, produced by a strain of *Pediococcus* in *kimchi*, was characterized to have bactericidal effects, and was resistant to *Micrococcus luteus*, *Clo. perfringens*, *Lis. monocytogenes*, *Sta. aureus*, *Esc. coli*, *Shi. flexneri* and *Sal. typhimurium* (Kwon et al., 2002). Lee et al. (2009) investigated the growth inhibitory effects of LAB species from *kimchi* on food-borne pathogens, and found strong antimicrobial activities against *Lis. monocytogenes*, *Sta. aureus*, *Esc. coli* and *Sal. typhimurium*. Fruits and vegetables fermented by lactobacilli strains in India and Romania showed antimicrobial activities against *Lis. monocytogenes*, *Esc. coli* (including ESBL strains), *Sta. aureus* and multi-drug resistant *Sta. aureus* (MRSA) strains (Grosu-Tudor and Zamfir, 2013; Patel et al., 2014).

An intervention programme on hospitalized children suffering from acute diarrhoea was conducted in New Delhi, India. The consumption of *dahi*, containing *Lac. lactis*, *Lac. lactis* subsp. *cremoris* and *Leu. mesenteroides* subsp. *cremoris* starter strains, significantly reduced the mean duration of diarrhoea in a randomized, double-blind study (Agarwal and Bhasin, 2002). *In vitro* screening of enterococci from *dahi* showed antimicrobial inhibition of food-borne pathogens, such as *Lis. monocytogenes*, *Sal. typhi*, *Sta. aureus* and *Shi. dysenteriae* (Gupta and Malik, 2007). Historically, the Maasai nomadic communities in Kenya have been consuming *kule naoto*, for the treatment of diarrhoea and constipation (Mathara et al., 2004).

In addition to the antibacterial activities of LAB in fermented foods, their antifungal properties have also been documented. Mould growth and mycotoxin production in food substances pose serious health risks and concerns to the consumers (Batish et al., 1997). Aflatoxins (AFs) and ochratoxins (OTs) are among the most potent mycotoxins reported so far with carcinogenic, mutagenic, teratogenic, neurotoxic, nephrotoxic, immunosuppressive and estrogenic effects when consumed, even at low concentrations (Bennett and Klich, 2003; IARC, 1993; Nwagu and Ire, 2011). Studies have shown the potentials of LAB as bio-protective cultures, in controlling or preventing mould growth and development, and their mycotoxins production in various fermented food matrices, thereby conferring significant health benefits on them.

Roger et al. (2015) confirmed the inhibition of the growth of *Asp. flavus* and its aflatoxin B_1 (AFB_1) metabolism by divergent LAB strains in *kutukutu*, a fermented maize dough in northern Cameroon. Carboxylic acids synthesized by *Lac. plantarum* FST1.7 and *Lac. brevis* R2Δ starter strains during wort fermentation were antagonistic against spores of mycotoxin-producing *Fusarium culmorum* (Peyer et al., 2016). Strains of *Lac. brevis* from *katak* (a yoghurt-like drink) in Bulgaria showed broad spectrum antifungal activities, suppressing the growth of carcinogenic *Asp. niger*, *Asp. awamori* and *Pen. claviforme*, and partially inhibiting mycelial growth and conidia germination of *Asp. flavus* (Tropcheva et al., 2014). Hassan and Bullerman (2008) earlier reported the anti-mycotoxigenic potentials of *Lac. paracasei* isolated from sourdough bread culture, against several species of *Aspergillus*, *Penicillium* and *Fusarium*. *Lac. brevis*, *Lac. plantarum* and *Lac. sanfranciscensis* strains used as starter cultures for cocoa fermentation, exhibited antifungal properties in the control of ochratoxinogenous *Asp. ochraceus*, *Asp. niger* and *Asp. carbonarius* (Essia Ngang et al., 2015). LAB present in naturally fermented *amahewu* and other fermented maize meal, potentially reduced AFB_1, fumonisin B_1 (FB_1) and zearalenone (ZEA) to undetectable levels (Chelule et al., 2010; Mokoena et al., 2005). The ability of some lactobacilli species, originating from fermented dairy foods, to bind AFB_1 was assessed. Specifically, *Lac. amylovorus* and *Lac. rhamnosus* strains bind more than 50% AFB_1 throughout a 72-h incubation period (Peltonen et al., 2001). Generally, the anti-mycotic compounds of LAB that make them active against mycotoxigenic moulds, include lactic acid, indole lactic acid, phenolic acid, phenyllactic acid, 4-hydroxy-phenyllactic acid, 3-(R)-hydroxydecanoic acid, 3-hydroxy-5-cis-dodecenoic acid, 3-(R)-hydroxydodecanoic acid, 3-(R)-hydroxytetradecanoic acid, cyclo (L-Phe-trans-4-OH-L-Pro), cyclo (L-Phe-L-Pro) and 3-hydroxylated fatty acids (Crowley et al., 2013; Haskard et al., 2001; Lavermicocca et al., 2000; Sjögren et al., 2003).

The production of antimicrobial compounds against pathogenic microorganisms, which cause various human diseases and other health related issues, has also been reported in fermented food products that are not lactic acid fermented. One example is the alkaline pH-fermented protein-rich legume foods that are widely consumed in West Africa sub-region and Southeast Asia. A number of traditional alkaline-fermented food condiments in West Africa like *bikalga*, *maari*, *okpehe* and *soumbala* have been found to possess health beneficial functions. They contain vegetative cells of *Bac. subtilis*, *Bac. pumilus*, *Bac. amyloliquefaciens* ssp. *plantarum*, *Bac. subtilis* subsp. *subtilis* and *Bac. licheniformis* that are capable of producing inhibitory peptide and antibiotic compounds. These substances such as iturin, fengycin, surfactin, difficidin, macrolactin, bacillaene, bacilysin, subtilisin, subtilosin A, subtilin, sublancin and ericin, showed broad spectrum antagonistic properties towards *Mic. luteus*, *Sta. aureus*, *Bac. cereus*, *Ent. faecium*, *Lis. monocytogenes*, *Esc. coli*, *Sal. typhimurium*, *Shi. dysenteriae*, *Yer. enterocolitica*, *Asp. ochraceus* and *Shi. flexneri* (Compaoré et al., 2013a; b; Kaboré et al., 2012; Oguntoyinbo et al., 2007; Ouoba et al., 2007). *Bac. natto* TK-1 and *Bacillus* strains from Japan, Korea and Thai fermented soybean foods, *natto*, *chungkookjang* and *thua-nao* respectively, produced heterogenous and bio-surfactant lipopeptides against *Bac. cereus*, *Lis. monocytogenes Ent. faecalis*, *Sal. typhimurium*, *Esc. coli* and *Sta. aureus*, including inhibition of *Asp. flavus* growth and significant detoxification of AFB_1 and ochratoxin A (OTA) by more than 70% (Cao et al., 2009a; Lee et al., 2016; Petchkongkaew et al., 2008). *Bac. subtilis* HJ18–4 isolated from buckwheat *sokseongjang*, a traditional Korean fermented soybean food, produced an antimicrobial peptide against *Bac. cereus*, causing the down-regulation of expression of diarrhoeal and enterotoxin genes (Eom et al., 2014).

Two strains of *Ent. faecium*, LMG 19827 and 19828 identified in Malaysian *tempe* produced enterocins that inhibited *Lis. monocytogenes* growth (Moreno et al., 2002). The antimicrobial potentials of Indonesian *tempe* was earlier demonstrated by its protective effects against diarrhoeal EPEC and enterotoxigenic *E. coli* (ETEC), with health beneficial functions in diarrhoea prevention, control and management among children (Karyadi and Lukito, 2000; Kiers et al., 2003; Kiers et al., 2002). Bacteriocin-producing *Bac. coagulans* was found in *ngari*, which inhibited *Bac. cereus*, *Sta. aureus* and *Mic. luteus* (Abdhul et al., 2015). A peptide antibiotic, polyxin, from *Paenibacillus polymyxa*, isolated from Argentinean fermented sausage, was previously found to be antagonistic to *Esc. coli*, *Sal. newport*, *Serratia marcescens*, *Sta. aureus*, *Kle. pneumoniae*, *Bac. thuringiensis israeliensis* and *Bac. cereus* (Piuri and Ruzal, 1998). Another *Pae. polymyxa* strain isolated from *kimchi*, co-produced a lantibiotic (polymyxin E1) and an antimicrobial peptide (paenibacillin) that were active against *Clo. sporogenes*, *Sta. aureus* and *Listeria* spp. (He et al., 2007).

Bioactive Compounds Synthesis

Different biologically active compounds, synthesized during food fermentations, either as metabolites of wild-type microbial strains/starter cultures or as substances released from the hydrolysis of organic components of food substrates, are widely associated with various functional health-promoting benefits. These bioactive compounds usually have antimicrobial (already discussed above), antihypertensive, antioxidant, anti-diabetic, anti-mutagenic, anti-cancer, anti-tumour effects and fibrinolytic activities.

Antihypertensive

Angiotensin converting enzyme-inhibitory (ACE-I) peptides are among the bioactive peptides formed during food fermentation by the action of proteolytic enzymes (i.e. proteases) on the native proteins present in many protein-based food substrates. They are not digested by the GIT digestive enzymes (e.g. trypsin, pepsin and chymotrypsin), and inhibit the enzyme responsible for converting angiotensin I to angiotensin II, a potent vasoconstrictor that causes re-absorption of water and sodium ions, thereby affecting the electrolyte balance, volume and blood pressure (BP) (Hartmann and Meisel, 2007; Rai et al., 2017). The inhibition of angiotensin converting enzyme (ACE) by ACE-I peptides is suggested to be made possible by the presence of hydrophobic (aromatic or branched side chain: Tyr, Phe, Trp, Ala, Ile, Val and Met) and positively charged amino acids (Arg and Lys), including Pro at the C terminal of ACE-I peptides, which show affinity for ACE protein (Haque and Chand, 2008; He et al., 2012; Rai et al., 2017). In addition to converting angiotensin I to angiotensin II, ACE also inactivates bradykinin and kallidin, two important vasodilators, which leads to increased BP, and risk of hypertension, including other cardiovascular diseases (CVD), strokes, etc (Sanjukta and Rai, 2016). Investigations on ACE-I peptides production are mostly on fermented milk products and legumes, and there are reports of their ACE inhibition, to cause vasodilator effects, which lowers BP. They are thus gaining wide popularity as antihypertensive agents in prophylactic medicine.

An *in vitro* spectrophotometric analysis is most commonly used for the evaluation of ACE-I activities. Hippuryl-His-Leu (HHL) serves as the substrate, which is hydrolysed by ACE to produce hippuric acid and His–Leu. ACE-I peptides in the water-soluble fraction, produced by bacterial cell wall proteinase enzymes system, prevents this reaction from taking place. ACE-I peptide activity is then expressed as the percentage of ACE inhibition or as the minimum concentration of peptide to inhibit 50% of ACE activity, the IC_{50} (Hernández-Ledesma et al., 2011). Several LAB strains have been screened for high proteinase and ACE-I activities of dipeptides, tripeptides and oligopeptides liberated from milk proteins, α_{s1}-casein and β-casein, as a strategy for the development of fermented milk foods with antihypertensive properties. Empirical studies on different LAB dairy and non-dairy starter cultures, alone or in combination with yeasts species, including wild-type strains, to ferment milk, for yoghurt, cheese and other traditional fermented milk products, as well as their specific ACE-I peptide sequences, properties and IC_{50} values after fermentation and during storage, have been documented (Beltrán-Barrientos et al., 2016; Rai et al., 2017). Li et al. (2017) characterized the ACE-I peptides in milk fermented with *Lac. casei* strains. More than half of the strains produced fermented milks with ACE-I activity of over 60%, and maximum Val-Pro-Pro (VPP) and Ile-Pro-Pro (IPP) concentration of 6.60 ± 0.25 μmol/L. Goat and camel milk fermented by *Lac. plantarum* 69 and *Lac. rhamnosus* MTCC 5945 (NS4), respectively had ACE-I activities up to 78.09% and 91.62%, under optimum fermentation conditions (Chen et al., 2018; Solanki and Hati, 2018).

To validate the *in vitro* antihypertensive potential of ACE-I peptides, animal models, using spontaneously hypertensive rats (SHR) and clinical trials of human subjects are conducted, measuring reduction or drop in systolic blood pressure (SBP) or diastolic blood pressure (DBP), after oral or intravenous/intra-peritoneal administration. Earlier works on fermented milk products, like *calpis* sour milk in Japan, fermented with *Lac. helveticus* and *Sac. cerevisiae*, and containing tripeptides VPP and IPP, showed hypotensive effects and decrease in ACE tissue activity of SHR (Nakamura et al., 1995; Nakamura et al., 1996). Milk fermented with *Lac. lactis* strains NRRL B-50571 or NRRL B-50572 had similar reductions in SBP and DBP of SHR, in comparison with captopril administration (Rodríguez-Figueroa et al., 2013). A single oral dose of *Lac. helveticus* H9 in fermented milk significantly lowered the systolic, diastolic and mean blood pressure of SHR (Chen et al., 2014). Increase in frequency unit of Gamalost cheese consumption, rich in ACE-I peptides, among Norwegian population, corresponded to a reduction in SBP of 0.72 mm Hg (Nilsen et al., 2014). Beltrán-Barrientos et al. (2018) examined the BP-lowering effect of milk fermented by *Lac. lactis* NRRL B-50571 in a double blind, randomized controlled, clinical trial of pre-hypertensive patients, administered daily for 5 wk, and observed reductions in SPB and DBP, in addition to triglyceride, total cholesterol and low density lipoprotein in blood serum. Other *in vivo* studies involving SHR and human subjects on both short- and long-term antihypertensive effects of fermented milk peptides are available in Beltrán-Barrientos et al. (2016) and Rai et al. (2017) reviews.

Similarly, protein-rich legume fermented seeds, particularly soybean, containing glycinin and β-conglycinin protein fractions, have also been reported to possess ACE-I peptides. But while information is available on the antihypertensive activities of different fermented soybean foods consumed in Asia, little or none is known about closely related fermented foods in Africa. For instance, an antihypertensive peptide identified in *natto*, fermented with *Bac. subtilis natto* O9516, showed *in vitro* ACE-I activity, and *in vivo* reduction of SBP within 5 h of single dose oral administration in SHR (Ibe et al., 2009). Extracts of *tofuyo* composed of Ile-Phe-Leu and Trp–Leu peptide sequences were resistant to GIT digestive enzyme treatments and had good ACE-I activity (Kuba et al., 2003). Toshiro et al. (2004) reported *chunggugjang* soy product to possess antihypertensive peptides, which when administered in volunteer human subjects reduced SBP and DBP by 15 mm Hg and 8 mm Hg, respectively after 2 h. ACE-I activity was recorded in *sufu*, fermented with fungal strain, which correlated with peptide content, and increased during fermentation and maturation (Ma et al., 2013). Pigeon pea seeds [*Cajanus cajan* (L.) Millsp.] fermented with a strain of proteolytic *Asp. niger*, produced an ACE-I octapeptide Val-Val-Ser-Leu-Ser-Ile-Pro-Arg, which had competitive inhibition against *in vitro* ACE activity (Nawaz et al., 2017). Fermented soymilk products with strains of *Lac. casei*, *Lac. acidophilus*, *Lac. bulgaricus*, *Ent. faecium* and *Bifidobacterium longum* have been shown to possess ACE-I properties (Martinez-Villaluenga et al., 2012; Tsai et al., 2008). In addition to milk and legume, fermented fish sauce from salmon, sardine, anchovy, blue mussel and oyster in Asia were reported to contain ACE-I peptides. A purified peptide from fermented blue mussel significantly reduced BP in SHR by oral administration (Je et al., 2005).

Gamma-aminobutyric acid (GABA) is another peptide compound with hypotensive activity, in addition to other physiological functions such as relaxation, sleep enhancement (opioid), anti-depression, enhanced immunity, anti-diabetic, anti-cancer and anti-obesity. GABA also possesses anti-inflammatory, pro-neurotransmitter, menopausal syndrome relief, activation of liver and kidney function, amelioration of oxidative stress, as well as treatments of Parkinson's disease, seizures, Alzheimer's disease, stiff-man syndrome and schizophrenia (Wong et al., 2003). It is a non-protein four-carbon free amino acid (FAA), synthesized by the irreversible α-decarboxylation of L-glutamic acid or its salts, i.e. monosodium glutamate (MSG), catalysed by glutamic acid decarboxylase (an enzyme found in bacteria, moulds and yeasts), in the presence of pyridoxal 5′ phosphate cofactor (Shelp et al., 1999). Evidence of GABA hypotensive effect on SHR was established in *Lac. plantarum*-fermented skim milk diet, where SBP and DBP were significantly decreased (Liu et al., 2011). *Lac. plantarum* produced 77.4 mg/kg of GABA in an enriched functional fermented milk food; this increased in concentration to 144.5 mg/kg, in combination with other LAB strains, and was recommended for mild hypertensive condition (Nejati et al., 2013). GABA concentration of 10–12 mg in 100 mL of milk fermented by *Lac. casei* strain Shirota and *Lac. lactis* YIT 2027, significantly decreased BP when fed two or four weeks in a randomized, placebo-controlled trial with mild hypertensive patients as participants (Inoue et al., 2003). *Lac. lactis* ssp. *lactis* improved the GABA content of cheese (16 mg of GABA/50 g cheese), which decreased BP by 3.5 mm Hg in human subjects (Pouliot-Mathieu et al., 2013). GABA and nattokinase in *Bac. subtilis* B060-fermented beans significantly lowered SBP and DBP in SHR and Wistar-Kyoto rats (Suwanmanon and Hsieh, 2014).

Antioxidant

Free radicals (i.e. atoms or molecules with an unpaired electron) and reactive oxygen species (ROS), such as superoxide anion radicals ($O\bullet_2^-$), hydroxyl radicals (HO•), hydrogen peroxide (H_2O_2) and singlet oxygen ($^1O_2$) are frequently generated in the human body during various metabolic processes and environmental stresses, besides those consumed in oxidized edible fats and oils. These free radicals play significant roles in cell signalling, apoptosis, gene expression and ion transportation (Lü et al., 2010). However, oxidative stress occurs when these molecules are produced in excess and/or there is lack of cellular defences against them, leading to oxidation of proteins and lipids, DNA mutation, cell and tissue disruption, permanent damage, and eventually death, as well as oxidative modification of low density lipoproteins (LDL) (Hu et al., 2004). Consequent upon this is the development of a number of degenerative diseases e.g. CVD (atherosclerosis), cancer, tumour growth, diabetes, arthritis, increase in blood cholesterol level, Alzheimer's and Parkinson's diseases (Afonso et al., 2007). Though not enough, the human system has non-enzymatic, i.e. reduced glutathione (GSH) and enzymatic antioxidants in the form of superoxide dismutase (SOD), glutathione peroxidase (GSHPx) and catalase (CAT), as defence and repair mechanisms against oxidative damages (Miller and Britigan, 1997). To alleviate oxidative stress, hydrolysed antioxidative peptides, FAA, free polyphenols (intermediates of β-glucosidase hydrolysis of polyphenols), genistein and daidzein (isoflavones), malvidin and delphinidin (flavonoids) and aglycones, which are naturally enhanced in fermented foods, can chelate metal ion, scavenge free radicals (by a way of proton or H^+ donation) and quench singlet oxygen (Mathew and Abraham, 2006). For peptides, the radical scavenging activity (RSA) is supported by the side chain groups of the amino acids residues, i.e. imidazole, indole and phenol in His, Trp and Tyr, respectively (Guo et al., 2009). Therefore, these bioactive compounds can serve anti-cancer, anti-tumour, anti-mutagenic and anti-diabetic purposes.

Fermentation of buckwheat, wheat gram, barley and rye with *Lac. rhamnosus* and *Sac. cerevisiae*, compared to their unfermented equivalents, led to increase in total phenolic content (TPC), and antioxidant activities (AOA) as assessed using 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging capacity, ferric ion-reducing antioxidant power (FRAP) and thiobarbituric acid (TBA) methods (Đorđević et al., 2010). Ethanolic extract of wheat *koji* prepared with *Asp. oryzae* and *Asp. awamori nakazawa* greatly increased the TPC and free RSA (Bhanja et al., 2009). Fermentation of adlay, chestnut, lotus seed and walnut cereal grains by food-grade *Bac. subtilis* and *Lac. plantarum* increased the phenolic and flavonoid contents of the methanolic extracts, with a stronger DPPH radical scavenging and FRAP activities (Wang et al., 2014). Solid-state fermentation (SSF) of wheat improved the water-soluble TPC and antioxidant property. There was a 14-fold improvement in TPC in *Asp. oryzae*-fermented wheat, as well as 6.6 and 5.0-fold enhancements of DPPH and ABTS radical scavenging, respectively in *Rhi. oryzae*-fermented wheat (Dey and Kuhad, 2014). The

TPC, total flavonoids and AOA were significantly enhanced in ethyl acetate extracts of SSF-fermented wheat using *Asp. oryzae* var. *effuses*, *Asp. oryzae* and *Asp. niger* (Cai et al., 2012).

During milk fermentation in the presence of *Leu. mesenteroides* ssp. *cremoris*, *Lac. jensenii* and *Lac. acidophilus* strains, antioxidative peptides released (4–20 kDa) were responsible for RSA and inhibition of lipid peroxidation (Virtanen et al., 2007). Low molecular weight bioactive peptides and FAA (His, Tyr, Thr and Lys) in commercial yoghurt provided antioxidant activities by inhibiting oxidation in a liposome model, in addition to possession of strong DPPH radical scavenging and high Fe^{2+} chelation (Farvin et al., 2010). An antioxidative undecapeptide (Ala-Arg-His-Pro-His-Pro-His-Leu-Ser-Phe-Met) isolated from milk fermented with *Lac. delbrueckii* subsp. *bulgaricus* strain demonstrated scavenging activity against DPPH radical (Kudoh et al., 2001). Soy whey fermented using *Lac. plantarum* B1-6 when compared to unfermented, possessed more TPC and isoflavone aglycone, higher ABTS, hydroxyl and superoxide RSA, ferric reducing antioxidant power, and greater protection against oxidative DNA damage (Xiao et al., 2015). Milk-*kefir* and soymilk-*kefir* fermented using *kefir* grains LAB and yeasts strains showed significant anti-mutagenic property against different mutagens, as a result of scavenging activity against DPPH radicals, inhibition of linoleic acid peroxidation and ferrous ion chelation (Liu et al., 2005).

Fermentation of soybeans to produce *tempe*, *natto*, *kinema* and *douchi* by mould or bacterial strains has also led to antioxidant effects in the methanolic extract or water-soluble fractions of these food products. Enhancement in TPC, DPPH scavenging activity, Fe^{3+} reducing power, Fe^{2+} chelation, inhibition of lipid peroxidation and oxidation of LDL correlated with increased FAA, peptide content, free isoflavones and phenolic acids, protease and β-glucosidase activities, in most of the investigations, suggesting their potential to mitigate oxidative stresses (Sanjukta and Rai, 2016). Earlier, free soluble phenol in fermented underutilized legume seeds significantly enhanced reducing power, DPPH scavenging ability and inhibition of lipid peroxidation more than the bound phenols (Oboh et al., 2009). The ethanolic extract of *Bac. subtilis* or *Asp. oryzae* fermented red beans decreased MDA as well as increased GSH and SOD in the liver tissue of Sprague–Dawley rats, while only *Bac. subtilis* extract increased the levels of ascorbic acid and α-tocopherol in the liver tissue; *Asp. oryzae* also increased ascorbic acid in the brain tissue better than the control (Chou et al., 2008). In an attempt to demonstrate the beneficial functions of antioxidant compounds in the management of diabetes mellitus (DM), Lim et al. (2012) assessed the *in vivo* anti-diabetic potential of fermented soybean extract with a *Bac. subtilis* strain, previously isolated from *chungkookjang*. Intra-peritoneal administration of the extract caused significant reduction in the plasma glucose level in addition to significant increases in plasma insulin level and activities of SOD, GSHPx, CAT and malondialdehyde (MDA) in streptozotocin (STZ)-induced diabetic rats, suggesting hyperglycemia inhibition (i.e. hypoglycemic action), due to the protection of pancreatic β-cells from free radical-mediated oxidative stress.

Anti-diabetic

Both *in vitro* and *in vivo* anti-diabetic effects of *meju* and *chungkookjang* fermented soybean products, rich in isoflavonoid aglycones and small peptides have been investigated. While peptide fractions in *chungkookjang* slightly enhanced glucose-stimulated insulin secretion, daidzein extract in *meju* and *chungkookjang* better improved insulin-stimulated glucose uptake by activating peroxisome proliferator-activated receptor-γ (PPAR-γ) in 3T3-L1 adipocytes than unfermented soybeans. Furthermore, mouse insulinoma (Min6) cells treated with genistein and peptides had greater glucose-stimulating insulin secretion capacity, as genistein and daidzein stimulated glucagon-like peptide-1 (GLP-1) secretion in enteroendocrine NCI-H716 cells, generating insulinotropic actions (Kwon et al., 2006, 2011). Experiments with type-2 diabetic male Sprague-Dawley (SD) rats fed *meju* and *chungkookjang*, prepared with microbial starter strains, significantly improved glucose homeostasis and tolerance, by way of glucose-stimulating insulin secretion and increased pancreatic β-cell mass, than the unfermented products (Yang et al., 2013; Yang et al., 2012). Fermented soybean diets, enriched with phenolic compounds, in STZ-induced diabetic rats reduced blood glucose, thiobarbituric acid reactive species (TBARS) contents, pancreatic MDA, α-amylase, intestinal β-glucosidase and acetylcholinesterase activities, with corresponding increase in pancreatic glutathione peroxidase (GPx) and GSH (Ademiluyi et al., 2014, 2015).

Anti-cancer

Apart from the lunasin anti-cancer peptide present in soybean, only very few reports are available on the anti-cancer compounds produced during food fermentation. Hydrophobic peptides in Korean traditional soy sauce displayed anti-tumour activity by their cytotoxic effects on different *in vitro* cell lines, including human colon cancer cells (Kim et al., 1998). *Bac. subtilis natto* T-2 and *Bac. natto* TK-1 in *natto* produced cyclic lipopeptide and lipopeptide bio-surfactant respectively, which induced apoptosis in human leukemia cells and inhibited the proliferation of human breast cancer cells (Cao et al., 2009b; Wang et al., 2007). Also, a surfactin-like compound from *Bac. subtilis* CSY 191-fermented *cheonggukjang* resulted in growth suppression of human breast cancer (MCF-7) cells (Lee et al., 2012). In camel milk fermented with *Lac. lactis* and *Lac. acidophilus* strains, the water-soluble extract ($\leq$3 kDa) significantly inhibited proliferation of Caco2, MCF-7 and HELA carcinoma cell lines (Ayyash et al., 2018). Fractionated peptides released by *Lac. helveticus* in fermented milk suppressed the growth of fibrosarcoma tumours induced by methylcholanthrene crystals, and increased the number of immunoglobulin A (IgA)-secreting cells in BALB/c mice (LeBlanc et al., 2002).

Fibrinolytic Enzymes

Developments in the study of fibrinolytic enzyme activities and its potential thrombolytic property started when Sumi et al. (1987) observed that one of the *natto* beans developed a clear zone on a fibrin plate, indicating that insoluble fibrin (i.e. blood clot) around the bean was digested by an unknown enzyme produced by *Bac. subtilis* (*natto*), which was thereafter characterized and named nattokinase (NK). Subsequently was the report of oral administration of NK in *natto* to healthy adults, which increased fibrinolytic activity two-folds in plasma, together with fibrin/fibrinogen degradation products in serum, and tissue plasminogen activator (tPA) (Sumi et al., 1990). In furtherance to this, Fujita et al. (1995) described the passage of NK through intestinal cells of rats, showing degradation of fibrinogen and appearance of NK in the plasma. Fibrinolytic enzymes from other protein-based fermented foods apart from *natto* include: choggokkinase from *chonggokjang*, myulchikinase from *myul-chi-jeot-gal*, katsuwokinase from *shiokara*, subtilisin DFE from *douhchi*, subtilisin DJ-4 from *doenjang*, metalloprotease from fish *jeotgal* and TPase from *tempe*. They are specific in their actions toward fibrin clots. Fibrin, the key protein constituent of blood clot, is formed following fibrinogen degradation by thrombin (Wolberg, 2007). Its presence is checked by fibrinolysis, to maintain a balance in homeostasis, by endogenous plasmin, which is activated from the non-active plasminogen by tPA. However, an imbalance situation arises in the human physiology, when there is challenge in hydrolysing fibrin. This results in its excessive accumulation in the blood vessels, which interfere with blood flow, to cause thrombosis, leading to myocardial infarction, ischemic heart disease, CVD, high BP and stroke (Mine et al., 2005).

For treatment purpose, different thrombolytic agents [e.g. urokinase, streptokinase, staphylokinase and tissue-type plasminogen activator (t-PA)] are available for clinical use, and they follow same mechanism for plasmin activation as previously described. They are however expensive, and suffer some drawbacks, such as short half-life in their specificity towards fibrin, gastrointestinal bleeding, allergic reactions, etc (Blann et al., 2002). Fibrinolytic enzymes produced by food-grade, edible microorganisms in traditional fermented foods that have the ability to degrade fibrin and inhibit thrombin, are cheap, highly specific toward fibrin, with safe records of consumption and no side effects. They have been isolated and characterized, and recommended as alternative therapy for the prevention and management of thrombosis (Kim et al., 1997; Montriwong et al., 2012; Singh et al., 2014; Stephani et al., 2017). However, much more than enzyme purification and identification, is the need for sufficient evidence-based and empirical scientific investigations to demonstrate the therapeutic efficacy of these enzymes in animal models and human subjects, involving clinical trials. Unfortunately, only very few studies exist on this aspect of therapeutic effectiveness. For example, subcutaneous administration of NK from *Bac. natto*, preceding intravenous kappa carrageenan to the tail of rats, produced infarcted regions that were significantly shorter in mean length in rats administered NK than those in control rats, signifying the anti-thrombosis prophylactic effects of NK (Kamiya et al., 2010). The fibrinolytic enzyme from *Stenotrophomonas* sp. in Indonesian soybean fermented food dissolved thrombin and reduced blood clot induced by κ-carrageenan injection in the tail of Wistar rats (Nailufar et al., 2016). In human subjects with cardiovascular risk factors, oral intake of NK for 2 months significantly decreased plasma levels of the CVD-associated coagulation factors of fibrinogen, factor VII and factor VIII (Hsia et al., 2009). Bacillopeptidase F preparations, a serine protease secreted by *Bac. subtilis* (natto) that was orally administered to human volunteers showed fibrinolytic and amidolytic activities by shortening euglobulin lysis time and positive changes in local blood flow (Omura et al., 2004).

Production of Exopolysaccharides (EPSs)

Complex polysaccharide metabolites are generally synthesized by wild-type microorganisms, autochthonous or starter cultures that are involved in the fermentation of different food substrates. Though these polysaccharides are secreted outside the microbial cells as extracellular metabolites, they are either adherent, remaining tightly bound to the cell wall surface appendages (e.g. capsule), referred to as capsular polysaccharides (CPSs) or permanently unattached to the cell surface as EPSs. EPSs may have two forms; those loosely attached to the bacterial surface and the ones freely released to the cell's external environment, which forms mucus, ropiness and slimy materials (Badel et al., 2011). Structurally, EPSs are long-chain, high molecular weight carbohydrate polymers, consisting of branched, repeating sugar units (mainly glucose, galactose and rhamnose), substituted sugars or sugar derivatives, including substituents such as phosphate and acetyl group (De Vuyst and Degeest, 1999; Du et al., 2017). They could be homopolysaccharides (HoPSs), composed of only one repeating monosaccharide moiety (D-glucose or D-fructose of two major groups: glucans and fructans), and examples are cellulose, dextran, mutan, alternan, pullulan, levan and curdlan, or heteropolysaccharides (HePSs), comprising different sugar molecules e.g. glucose, galactose, rhamnose, mannose, *N*-acetylglucosamine, *N*-acetylgalactosamine and glucuronic acid, to form gellan and xanthan (Fabera et al., 1998; Laws et al., 2001). Because the biosynthesis of EPSs is a complex one, and the fact that the mechanism of polymerization of the repeating unit is unclear, its discussion remains out of the scope of this review.

Other than the technological properties (i.e. viscosity, texture, rheology and firmness) of EPSs in fermented foods, they have been reportedly found to impart a number of physiological and health beneficial functions on the consumers, which include adhesion and colonization of probiotic microorganisms for competitive exclusion of food-borne pathogens, prebiotic activity, acting as a physical barrier to many pathogenic bacteria. Other health benefits include serum and blood cholesterol reduction, immunomodulation and immunostimulatory effects, antimicrobial, antioxidant, antihypertensive, anti-diabetic, anti-cancer, anti-tumour, antiproliferative, anti-allergic, anti-ulcer, anti-viral, anti-biofilm formation of pathogens, generation of short chain fatty acids (SCFAs) upon degradation in the gut by the colon microbiota, and protection against the harsh gut environment (Caggianiello et al., 2016; Dilna et al., 2015).

Purified EPS (EPS_DN1) produced by *Lac. kefiranofaciens* in *kefir* completely inhibited *Lis. monocytogenes* and *Sal.* Enteritidis at 1% least concentration, exerting bactericidal effects against them *in vitro* (Jeong et al., 2017). EPSs of *Leu. citreum*, *Leu. mesenteroides*, *Leu. pseudomesenteroides* and *Ped. pentosaceus* obtained from Tunisian fermented foods showed pre- and post anti-biofilm activities at 1 mg/mL against *Esc. coli*, *Ent. faecalis* and *Sta. aureus*, with minimum adhesion inhibition of 86.9% and 53.4% for *in vitro* pre- and post-treatments, respectively (Abid et al., 2018).

Lac. plantarum LRCC5310 isolated from *kimchi* produced an EPS that had anti-rotavirus effect against human rotavirus (HRV) Wa strain. At 1.95 mg/mL, it reduced the viral RNA copy numbers significantly, when compared to the control; it also caused cytopathic effects and interference towards the viral cells, due to strong adherence to MA104 cell lines. In the *in vivo* study with the same EPS but rotavirus EDIM (RV-EDIM) strain, neonate mice pre-treated with EPS for 2 d, followed by administration of RV-EDIM together with EPS at 1 mg/mouse for 5 d, significantly lowered the number (50%) that developed RV-EDIM-induced diarrhoea than in control (Kim et al., 2018). For mice with acute diarrhoea and severe dehydration, the mean diarrhoea score and rotavirus shedding with this EPS also decreased significantly at 8 d post-infection in comparison with those in control (Kim et al., 2018). The EPS of *Lac. delbrueckii* ssp. *bulgaricus* 1073R-1 from traditional Bulgarian yoghurt at 20 μg/d orally administrated to BALB/c mice for 21 d, prior to intranasal infection, significantly decreased influenza virus (H1N1) titre, and increased its antibodies (IgA, IgG_1) at 4 d post-infection, when compared to the control (Nagai et al., 2011). However, the acidic EPS (APS) prolonged the survival rate of influenza virus-infected mice, and not the neutral EPS (NPS).

EPS prepared from *Lac. plantarum* YW11 used to ferment Tibetan *kefir* showed *in vitro* AOA against hydroxyl radicals at 75% of 1.22 mg/mL, superoxide anion at 62.71% of 1.54 mg/mL, DPPH at 35.11% of 0.63 mg/mL, and 41.09% ferrous ion chelation at 1.07 mg/mL concentration. In the oxidant-induced stress experiment by subcutaneous injection of 500 mg/kg per day of 5% D-galactose in an ageing mouse, followed by 2.5 mg/mL EPS of *Lac. plantarum* YW11, there was a significant reduction in serum MDA, which reflects lipid oxidation inhibition as well as increased GSHPx, SOD, CAT and total antioxidant capacity (TAOC) activities (Zhang et al., 2017). Pyrosequencing data analysis of the gut microbiota of the ageing mouse revealed gut modulation and improvement, where *Lac. plantarum* YW11 EPS recovered the microbiome and phylotypes initially decreased or eliminated by D-galactose, with further increase in SCFAs content (Zhang et al., 2017). *Wei. confusa* OF126 strain isolated from *ogi*, having EPS of 1.1 x 10^6 Da exhibited hydroxyl radical and DPPH activities of 86.5% and 67.4%, respectively at 4 mg/mL (Adesulu-Dahunsi et al., 2018). *Ent. faecium* BDU7 cultured from *ngari* was assayed for EPS; its purified form (8 mg/mL) showed significant scavenging of DPPH (63.5%), superoxide anion (77.3%) and hydroxyl (38.4%) radicals (Abdhul et al., 2015). The antioxidant activity of a purified EPS (6.9 x 10^5 Da) from *Lac. lactis* subsp. *lactis* in Chinese pickled cabbage, revealed significant decrease in MDA and increased SOD and CAT in mice serum in a concentration-dependent manner (Pan and Mei, 2010). An EPS (LPC-1) extracted from *Lac. plantarum* C88 found in Chinese dairy *tofu*, demonstrated strong RSA of 85.21% hydroxyl radical and 52.23% DPPH at 4 mg/mL. LPC-1 also significantly inhibited the formation of MDA and exerted AOA against H_2O_2-induced injury in Caco-2 cells (Zhang et al., 2013).

Wang et al. (2018) characterized a neutral EPS (EPS0142) produced by *Lac. plantarum* JLK0142 from *tofu*. EPS0142 significantly induced macrophage-derived nitric oxide (NO) production in RAW 264.7 cell lines, in a dose-dependent manner, without any cytotoxic effect, as well as improved phagocytic activity. High dose of EPS0142 also administered to previously cyclophosphamide-induced immunosuppressed female BALB/c mice, significantly increased the spleen index and splenic lymphocyte proliferation, including the intestinal immunoglobulin A (sIgA) content and the levels of IL-2 and TNF-α cytokines. EPS extracted from milk fermented with *Lac. lactis* subsp. *cremoris* FC, and orally administered to male BALB/c mice before skin exposure to 2,4,6-trinitro-1-chlorobenzene (TNCB), significantly suppressed skin thickening induced by TNCB and penetration of mast cells in skin lesions (Gotoh et al., 2017). There was also the regulation of IL-4, IFN-γ, IL-6 and TNF-α over-expression, as a result of TNCB exposure, and stimulation of bone marrow cell proliferation in dose-dependent EPS-treated Payer's patch cell of C3H/HeJ mice. EPS derived from *Lac. delbrueckii* ssp. *bulgaricus* 1073R-1 as previously described, and the respective yoghurt product, caused immunostimulation of IFN-γ and augmentation of NK cells production in female BALB/c mice spleen cells, but not other yoghurts that also contain lactobacilli cultures (Makino et al., 2006, 2016). EPS fraction (B-EPS) from *Bac. subtilis* J92 isolated from *kimchi* increased NO, TNF-α, IL-6 and IL-1β, and their proteins and mRNA expressions in IFN-γ-primed RAW 264.7 macrophages cell lines, including cytokine (IL-2 and IFN-γ) production by CD3/CD28-stimulated splenocytes (Jung et al., 2015). In addition, post-orally administered B-EPS significantly lowered the immunosuppression effects of cyclophosphamide in mice thymus and spleen, in a concentration-dependent manner.

EPS-producing *Str. thermophilus* strains in fermented milk, as well as their purified EPS in sterile milk, prevented the development of gastritis ulcer, when previously fed to BALB/c mice for 7 d before acetyl-salicylic acid (ASA)-induced gastritis, based on histological parameters and immune responses (Rodríguez et al., 2009). Two novel homogeneous EPSs synthesized by *Lac. casei* SB27 that was previously isolated from fermented *yak* milk, significantly inhibited the proliferation of HT-29 colorectal cancer cells, as an anti-tumuor agent; induced apoptosis by the activation of *caspase-3* and *-8* genes in addition to up-regulation of pro-apoptotic genes *Bad* and *Bax* (Di et al., 2017). EPS of probiotic *Ent. faecium* K1, an isolate from a traditional fermented milk product, *kalarei*, showed significant cholesterol reduction potential, lowering the concentration from 100% to 48.81% *in vitro* (Bhat and Bajaj, 2018). *Lac. delbrueckii* subsp. *bulgaricus* strains from homemade yoghurt that produced high amount of EPS, removed more cholesterol from the medium, compared to those strains with low EPS production (Tok and Aslim, 2010).

Probiotic Properties of Fermented Foods

Probiotics are defined as preparation of live microorganisms, which when consumed in adequate amounts (10^7–10^9 cfu/g or mL), induce health beneficial effects by qualitatively or quantitatively influencing gut microbiota, modifying immune status and contributing to general well being of the host, beyond basic nutrition (FAO/WHO, 2002; Pipenbaher et al., 2009). Most fermented foods and beverages contain high population of viable microorganisms, and they serve as vehicles for the delivery of probiotics. For a probiotic microorganism to exert health benefits and other positive desirable effects on the host when administered, it is expected to be resistant to gastric acidity of the stomach and tolerant to bile salts of the small intestine, produce antimicrobial compounds against pathogenic microorganisms, adhere to GIT mucosal and epithelial cell linings, as well as *in vivo* persistence (colonization) for competitive exclusion of pathogens, in addition to a long history of safety and non-pathogenicity (Ouwehand et al., 2002).

Even though the precise mechanisms by which probiotics perform their functions in the host have not been fully elucidated, some manner of probiotic functions has been proposed. These include up-regulation of immune responses (e.g. IgA) towards pathogens or vaccines, down regulation of inflammatory responses, production of bacteriocins and SCFAs, improving gut mucosal barrier function, enhanced stability and recovery of commensal microbiota when disturbed, as well as modulation of host gene expression and delivery of functional proteins (e.g. lactase) (Sanders, 2009). A probiotic *Lac. gasseri* SBT2055 used to prepare fermented milk significantly reduced abdominal visceral and subcutaneous fat, weight and body mass index (BMI) in adults with obese tendencies, in a randomized controlled trial (Kadooka et al., 2010). Fermented milk curd containing probiotic *Lac. acidophilus*, *Lac. casei* and *Lac. lactis* biovar *diacetylactis* had anti-tumour effect in rats, inhibiting 1,2-dimethylhydrazine (DMH) colon genotoxic compound, as a result of significant reduction in DNA damage, in comparison to the control (Kumar et al., 2010). The anti-diabetic effect of *dahi* fermented with probiotic *Lac. acidophilus* and *Lac. casei* was evaluated in high fructose-induced type-2 diabetic male albino Wistar rats. *Dahi*-supplemented diet significantly reduced blood glucose, glycosylated hemoglobin, glucose intolerance, plasma insulin, liver glycogen, plasma total cholesterol, triacylglycerol, low density lipoprotein cholesterol (LDL-C), very low density lipoprotein cholesterol (vLDL-C), and blood free fatty acids that were initially increased after high fructose feeding (Yadav et al., 2007). High cholesterol diet supplemented with cereal-mix fermented food containing probiotic *Pic. kudriavzevii* OG32, significantly lowered serum total cholesterol, triacylglycerol and LDL-C in rats, when compared to the control high cholesterol feed without probiotic supplementation (Ogunremi et al., 2015). Total serum and liver cholesterol, including the atherogenic index of rats fed high cholesterol chow, supplemented with milk fermented by probiotic *Lac. plantarum* HLX37, significantly decreased by 23.33%, 32.37% and 40.23% respectively, when compared to the hyperlipidemia diet (Guan et al., 2017). Probiotic bacteria in fermented milk were able to maintain consistent microbial community shift in the human GIT, where *Bacteriodetes* species increased during the intervention programme (Unno et al., 2015). Chung et al. (2014) investigated the effects of probiotic *Lac. helveticus*-fermented milk on cognitive functions in healthy older adults, in a double-blind, randomized control experiment. Their results showed an improvement in cognitive functioning, in relation to neuropsychological and cognitive fatigue.

Conclusion

Fermented foods and beverages constitute a significant component of human nutrition, dietary supply and calories intake in different parts of the world. Fermentation of diverse plant and animal substrates by microorganisms and their enzymes provides desirable features, such as post-harvest preservation of perishable food materials, nutritional enrichment, bio-preservative effects and specific health-promoting benefits. Nowadays, fermented foods and beverages are consumed not only for nutritional values, wholesomeness or palatability, but importantly for their health beneficial functions. Live microorganisms and/or their metabolites in fermented foods are responsible for various health-promoting properties. An example is lactic acid, the primary metabolite in non-alcoholic fermented cereal foods ($pH < 4.2$) that demonstrates potential health benefits, by inhibiting pathogens causing food-borne diseases and human illnesses. Bioactive peptides, free amino acids and polyphenols, flavonoids, isoflavones and enzymes, which are naturally enriched in fermented foods possess antimicrobial, antihypertensive, antioxidant, anti-diabetic, anti-cancer, anti-tumour, anti-mutagenic, anti-proliferative and anti-thrombosis health benefitting properties. In addition, exopolysaccharides (EPSs) consumed in fermented foods can serve as prebiotics; they are also metabolized by colon microbiota to produce short chain fatty acids (SCFAs), which induce apoptosis of cancer cells and stimulate immune responses in the host. Furthermore, fermented foods contain viable probiotic microorganisms that confer health benefits on the host. However, to justify their development as functional foods and nutraceuticals, there is need for further and detailed scientific investigations on the in-depth characterization of the bioactive compounds and mechanism of actions in animal models and human intervention programmes, involving clinical trials.

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