Received: 20 July 2019 | Revised: 17 November 2019 | Accepted: 18 November 2019

DOI: 10.1111/1541-4337.12520

COMPREHENSIVE REVIEWS IN FOOD SCIENCE AND FOOD SAFETY

Comprehensive REVIEWS in Food Science and Food Safety WILEY

Fermented foods in a global age: East meets West

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Abstract

Fermented foods and alcoholic beverages have long been an important part of the human diet in nearly every culture on every continent. These foods are often well-preserved and serve as stable and significant sources of proteins, vitamins, minerals, and other nutrients. Despite these common features, however, many differences exist with respect to substrates and products and the types of microbes involved in the manufacture of fermented foods and beverages produced globally. In this review, we describe these differences and consider the influence of geography and industrialization on fermented foods manufacture. Whereas fermented foods produced in Europe, North America, Australia, and New Zealand usually depend on defined starter cultures, those made in Asia and Africa often rely on spontaneous fermentation. Likewise, in developing countries, fermented foods are not often commercially produced on an industrial scale. Although many fermented products rely on autochthonous microbes present in the raw material, for other products, the introduction of starter culture technology has led to greater consistency, safety, and quality. The diversity and function of microbes present in a wide range of fermented foods can now be examined in detail using molecular and other omic approaches. The nutritional value of fermented foods is now well-appreciated, especially in resource-poor regions where yoghurt and other fermented foods can improve public health and provide opportunities for economic development. Manufacturers of fermented foods, whether small or large, should follow Good Manufacturing Practices and have sustainable development goals. Ultimately, preferences for fermented foods and beverages depend on dietary habits of consumers, as well as regional agricultural conditions and availability of resources.

KEYWORDS

fermentation, fermented foods and beverages, genomics, lactic acid bacteria, starter cultures

1 | INTRODUCTION

Fermented foods have been consumed by humans for thousands of years. Although they were likely produced initially as a means of preservation, it would have been readily apparent that these foods possessed other desirable attributes. Compared to the raw ingredients from which they are made, fermented foods have unique flavors, textures, appearances, and functionalities. Even many centuries ago, well before the advent of nutrition science, fermented foods would have been intentionally produced as a stable source of vitamins, minerals, calories, and other nutrients (Steinkraus, 1994).

Remarkably, the discovery that fermentation enhances food preservation, quality, and functionality occurred independently on every continent and nearly at the same time in human history. Thus, evidence for viticulture and wine-making during the Neolithic period has been detected in the Middle East, Asia, and the Far East (Li et al., 2018; McGovern et al., 2004; McGovern et al., 2017; McGovern, Glusker, Exner, & Voigt, 1996). Later, wine-making spread to the Mediterranean regions of Europe (Legras, Merdinoglu, Cornuet, & Karst, 2007). Similar pan-continental origins were reported for beer, bread, and vegetable fermentations (Valamoti, 2018; Wang et al., 2018; Lee & Kim, 2016; Pasqualone, 2018; Tamang & Samuel, 2010).

In contrast, other fermented foods appear to have originated and developed in particular locations. For example, wherever pastoral agricultural practices and animal husbandry prevailed, milk from cows, sheep, goats, and other animals was often available. Thus, cultured milk, cheese, and fermented dairy products evolved throughout the Middle East, Europe, and India. In contrast, in China, Japan, Korea, and other Far East regions, animal agriculture was more limited. Social, cultural, religious, and economic factors also influenced the types of substrates used to produce fermented foods and alcoholic beverages (Hesseltine & Wang, 1980). Thus, the fermented foods that evolved in Asia were based more often on rice and grains, soybeans, vegetables, and fish as the primary substrates. Finally, in Africa, cereal grains endemic to specific regions, including millet, sorghum, maize, and wheat, remain common food fermentation substrates. Cassava and other root crops have long been consumed as staple fermented foods in the dietary cultures of Africa. The geographical distribution of preparation and consumption of fermented foods and alcoholic drinks in the world are summarized in Table 1A-H.

Raw materials and provenance are not the only distinguishing features that influence the myriad varieties of fermented foods produced around the world. In particular, modernization, including automation, emphasis on safety, and integration of hygienic standards, has had profound effects on the food fermentation industry (Oguntoyinbo, 2014). However, perhaps the most important development in the fermented food and beverage industry has been the introduction of starter cultures. Indeed, starter cultures and associated technologies that began in the West are now used around the world. Accordingly, genomic tools are also now being used to study relevant microbes and microbial communities in nearly every category of fermented foods.

In this review, we will describe historical and cultural aspects of fermented foods and beverages produced around the world. How modernization and mechanization has influenced the manufacture of fermented foods will be discussed. Next, we will consider specific categories of fermented foods and beverages and how substrates, cultures, and microbes, and technologies distinguish these products from different regions. This discussion will focus on how greater consistency can be achieved and the potential use of novel starter cultures. How genomics, metabolomics, and other modern approaches are being used to characterize microbiomes in fermented foods will be reviewed. Future prospects will also be reviewed, including discussion on how the manufacture of traditional, but less studied fermented foods and alcoholic beverages can be standardized with an emphasis on hygiene and improved public health. Finally, we will address how fermented foods are now being intentionally developed to deliver health benefits to under-served communities. Importantly, throughout this review, we define fermented foods and beverages, broadly, as those foods or beverages made by controlled microbial growth and enzymatic conversions (Marco et al., 2017).

2 | HUMAN HISTORY, CULTURE, AND FERMENTED FOODS

Every community and every region on every continent have unique and distinct food and dietary habits based on their own specific cultures and accessibility to edible raw resources of plant/animal origins (Figure 1). Religions, races, and ethnicities, in particular, have a strong influence on food habits. Thus, taboos and other restrictions are imposed on a wide range of foods and beverages, including pork and other meats, animal milk, and alcohol. In general, food habits can be categorized into three major dietary cultures in the world, based on the predominant type of cereal-based foods consumed in those regions: (a) steamed rice as the main staple food in East Asia, (b) loaves/breads based on wheat or barley in Western Asia, Europe, North America, and Australia, and (c) porridges prepared from sorghum or maize in Africa and South America (Tamang & Samuel, 2010), and also cassava and root/tuber-based staple foods in Africa. Alternatively, consumption of animal milk can also distinguish cultural differences. Thus, whereas milk and dairy food consumption is common among Europeans, Indians, Semites, and North Central Asians, animal milk is rarely consumed by the majority of Mongolian-origin, and other far eastern Asian communities (Laufer, 1914).

For fermented foods, in particular, how fermentation is initiated provides yet another way to distinguish between different cultures. For most of human history, fermented foods and alcoholic beverages were produced from plant or animal sources by traditional fermentation (i.e., in the absence of a starter culture). Fermentation relied on either natural or spontaneous fermentation or the back-slopping method where portions of a previously fermented product were added to a fresh substrate (Campbell-Platt, 1987; Steinkraus, 1996; Tamang, 2010a). It has been estimated that majority of traditional fermented foods and alcoholic beverages are still

TABLE 1 Geographical distribution of preparation and consumption of fermented foods and alcoholic drinks in the world (Hesseltine 1983; Campbell-Platt 1987; Steinkarus 1996; Alexandraki et al. 2013; Franz et al. 2014; Tamang et al. 2016a; Tamang 2010a, 2010b, 2016a; Rezac et al. 2018)

A. Fermented milk products			
Country	**Substrate**	**Food**	**Organoleptic characters and culinary**
Mongolia	Mare or camel milk	*Airag*	Acidic, sour, mild alcoholic drink
South Africa, Zimbabwe	Cow milk	*Amasi*	Acidic, sour, with thick consistency
Worldwide	Animal milk	*Cheese*	Soft or hard, solid; side dish, salad, used in many cooked/baked dishes
India, Nepal, Bhutan, China (Tibet)	Yak/cow milk	*Chhu*	Cheese like product, curry, soup
India, Nepal, Bhutan, China (Tibet)	Yak/cow milk	*Chhurpi*	Cheese like product, soup, curry, pickle
India, Nepal, Sri Lanka, Bangladesh, Pakistan	Cow/buffalo milk, starter culture	*Dahi*	Curd, savory
Indonesia	Buffalo milk	*Dadih*	Curd, savory
Russia	Goat, sheep, cow	*Kefir*	Alcoholic fermented milk, effervescent milk
Russia	Animal Milk	*Koumiss*	Acid fermented milk, drink
Egypt	Milk	*Laban rayeb*	Acid fermented milk, yoghurt-like
North, East Central Africa	Cow milk	*Leben/Lben*	Sour milk
India, Bangladesh	Buffalo/cow milk	*Misti dahi (mishti doi, lal dahi, payodhi)*	Mild-acidic, thick-gel, sweetened curd, savory
Ghana	Raw cow milk	*Nunu*	Naturally fermented milk
India, Nepal, Tibet (China)	Cow/yak milk	*Philu*	Cream like product, curry
India	Cow, buffalo milk	*Shrikhand*	Acidic, concentrated sweetened viscous, savory
India, Nepal	Yak or cow milk	*Somar*	Buttermilk
Vietnam	Dried skim milk, starter, sugar	*Sua chua*	Acid fermented milk
Mongolia	Cow/yak/goat milk	*Tarag*	Acidic, sour, drink
Finland	Cow milk	*Viili*	Thick, sticky, sweet taste, breakfast
Europe, Australia, America	Animal milk	Yogurt	Acidic, thick-gel viscous, Curd-like product, savory
B. Fermented Cereal Foods			
Country	**Substrate**	**Food**	**Organoleptic characters and culinary**
China, Taiwan, Thailand, Philippines	Red rice	*Ang-kak*	Colorant
Bulgaria	Cereals	*Boza*	Sour refreshing liquid
East Africa, Kenya	Maize, sorghum, millet	*Busa*	Submerged
Burkina Faso, Ghana	Pearl millet	*Ben-saalga*	Weaning food
India, Sri Lanka, Malaysia, Singapore	Rice and black gram	*Dosa*	Thin, crisp pancake, Shallow-fried, staple
Ethiopia	Tef flour, wheat	*Enjera/Injera*	Acidic, sourdough, leavened, pancake-like bread, staple
Benin	Maize	*Gowé*	Intermediate product used to prepare beverages, porridges
Sudan	Sorghum	*Hussuwa*	Cooked dough
India, Sri Lanka, Malaysia, Singapore	Rice, black gram or other dehusked pulses	*Idli*	Mild-acidic, soft, moist, spongy pudding; staple, breakfast
India, Nepal, Pakistan	Wheat flour	*Jalebi*	Crispy sweet, doughnut-like, deep-fried, snacks
Ghana	Maize	*Kenkey*	Acidic, solid, steamed dumpling, staple
Thailand	Glutinous rice, *Look-pang* (starter)	*Khamak (Kao-mak)*	Dessert

(Continues)

TABLE 1 (Continued)

B. Fermented Cereal Foods			
Country	**Substrate**	**Food**	**Organoleptic characters and culinary**
Nigeria	Maize, sorghum, millet	*Kunu-zaki*	Mild-acidic, viscous, porridge, staple
Sudan	Sorghum	*Kisra*	Thin pancake bread, staple
Ghana	Maize	*Koko*	Porridge
China	Rice	*Lao-chao*	Paste, soft, juicy, glutinous dessert
Benin, Togo	Maize	*Mawè*	Intermediate product used to prepare beverages and porridges
Tanzania	Maize, sorghum, millet	*Mbege*	Submerged
Nigeria	Maize, sorghum, millet	*Ogi*	Mild-acidic, viscous, porridge, staple
West Africa	Maize, sorghum	*Pito*	Submerged
Congo	Maize	*Poto poto*	Slurry
Mexico	Maize	*Pozol*	Porridge, staple, food
Philippines	Rice	*Puto*	Steamed cake, breakfast
India, Pakistan	Buffalo or cow milk and cereals, pulses	*Rabadi*	Mild-acidic, thick slurry-like product
India, Nepal, Bhutan	Rice-wheat flour-milk	*Selroti*	Pretzel-like, deep fried bread, staple
America, Europe, Australia	Rye, wheat	*Sourdough*	Mild-acidic, leavened bread
Indonesia	Glutinous rice, *Ragi*	*Tape Ketan*	Sweet, sour, mild alcoholic, dessert
Tanzania	Cassava, maize, sorghum, millet	*Togwa*	Fermented gruel or beverage
Cyprus, Greece, Turkey	Sheep milk, wheat	*Tarhana*	Mild-acidic, sweet-sour, soup base
Kenya, Uganda, Tanzania	Maize, sorghum, millet, cassava flour	*Uji*	Acidic, sour, porridge, staple

C. Fermented Vegetable Products			
Country	**Substrate**	**Food**	**Organoleptic characters and culinary**
Philippines	Mustard	*Burong mustala*	Acidic, wet
Spain	Cupers	*Cupers (fermented)*	Acidic, wet, side-dish
Europe, USA, Canada	Cucumbers	*Cucumbers* (fermented)	Acidic, wet, pickle
Vietnam	Mustard and beet, eggplant	*Dha muoi*	Acidic, wet
India	Bamboo shoot	*Ekung*	Acidic, sour, soft, curry
India	Bamboo shoot	*Eup*	Acidic, sour, dry, curry
Taiwan	Mustard	*Fu-tsai*	Acidic, sour
India, Nepal	Wild vegetable	*Goyang*	Acidic, sour, wet, soup
India, Nepal, Bhutan	Leafy vegetable	*Gundruk*	Acidic, sour, dry, soup, side-dish
India	Bamboo shoot tips	*Hirring*	Acidic, sour, wet, pickle
Thailand	Red onion	*Hom-dong*	Fermented red onion
Taiwan	Cucumber	*Jiang-gua*	Fermented cucumber, pickle
Taiwan	Bamboo shoot, salt, sugar, *douchi* (fermented soybeans)	*Jiang-sun*	Fermented bamboo; side dish
India, Nepal	Cucumber	*Khalpi*	Acidic, sour, wet, pickle
Korea	Cabbage, green onion, hot pepper, ginger	*Kimchi*	Acidic, mild-sour, wet, side-dish
Thailand	Bamboo shoots	*Naw-mai-dong*	Acidic, wet
India, Nepal, Bhutan	Bamboo shoot	*Mesu*	Acidic, sour, wet
Korea	Cucumber, salt, water	*Oiji*	Fermented cucumber

(Continues)

TABLE 1 (Continued)

C. Fermented Vegetable Products			
Country	**Substrate**	**Food**	**Organoleptic characters and culinary**
USA, Spain, Portugal, Peru, Chile	Olive	*Olives* (fermented)	Acidic, wet, salad, side dish
Thailand	Leafy vegetable, salt, boiled rice	*Pak-gard-dong*	Acidic, wet, side dish
Thailand	Leaves of *Gynandropis pentaphylla*	*Pak-sian-dong*	Acidic, wet, side dish
China	Cabbage	*Pao cai*	Sweet and sour rather than spicy, Breakfast
Europe, USA, Canada, Australia	Cabbage	*Sauerkraut*	Acidic, sour, wet, salad, side dish
Indonesia	Mustard leaves, cabbage, salt, coconut	*Sayur asin*	Acidic, sour, wet, salad
India	Bamboo shoot	*Soibum*	Acidic, sour, soft, curry
India	Bamboo shoot tips	*Soidon*	Acidic, sour, soft, curry
India, Nepal, Bhutan	Radish tap-root	*Sinki*	Acidic, sour, dry, soup, pickle
China	Vegetables	*Suan-cai*	Acidic, sour, wet
Taiwan	Mustard	*Suan-tsai*	Acidic, sour, dry
Japan	Turnip	*Sunki*	Acidic, sour, wet
Japan	Japanese radish, salt, sugar, *Shochu*	*Takuanzuke*	Pickle radish
India	Bamboo shoot	*Tuaithur*	Solid, wet, sour, curry
D. Fermented Legume Foods			
Country	**Substrate**	**Food**	**Organoleptic characters and culinary**
India	Soybean	*Bekang*	Alkaline, sticky, paste, curry
India	Black gram	*Bhallae*	Mild acidic, side dish
Burkina Faso	Roselle (*Hibiscus sabdariffa*)	*Bikalga*	Condiment
Korea	Soybean	*Chungkokjang* (or *jeonkukjang, cheonggukjang*	Alkaline, sticky, soup
Ghana, Nigeria	Locust bean	*Dawadawa*	Alkaline, sticky
India	Bengal gram	*Dhokla*	Mild acidic, spongy, steamed, snack
China, Taiwan	Soybean	*Douchi*	Alkaline, paste
Korea	Soybean	*Doenjang*	Alkaline, paste, soup
China	Soybean curd	*Furu*	Mild acidic
Korea	Soybean, red pepper	*Gochujang*	Hot-flavored seasoning
India	Soybean	*Hawaijar*	Alkaline, sticky
Nigeria, Benin	Locust bean	*Iru*	Alkaline, sticky
Korea	Soybean, *meju*, salt, water	*Kanjang*	Soya sauce
Sudan	Leaves of legume (*Cassia* sp.)	*Kawal*	Alkaline, strong flavoured, dried balls
Indonesia	Soybean, wheat	*Kecap*	Liquid
Indonesia	Soybean (black)	*Ketjap*	Syrup
Sierra Leone	Locust bean	*Kinda*	Alkaline, sticky
India, Nepal, Bhutan	Soybean	*Kinema*	Alkaline, sticky; curry
Nepal, India	Black gram	*Maseura*	Dry, ball-like, brittle, condiment
China, Taiwan	Soybean	*Meitauza*	Liquid

(Continues)

TABLE 1 (Continued)

D. Fermented Legume Foods			
Country	**Substrate**	**Food**	**Organoleptic characters and culinary**
Korea	Soybean	*Meju*	Alkaline, paste
Japan	Soybean	*Miso*	Alkaline, paste
Japan	Soybean	*Natto*	Alkaline, sticky, breakfast
Indonesia	Peanut press cake, tapioca, soybean curd starter	*Oncom Hitam* (Black *Oncom*) and *Oncom Merah* (Orange *Oncom)*	Fermented peanut press cake, roasted or fried
West, East and Central Africa	Melon Seeds, castor oil seeds, pumpkin bean, sesame	*Ogiri/Ogili*	
Nigeria	Seeds from *Prosopis africana*	*Okpehe*	Alkaline, sticky
Burkina Faso	Locust bean	*Soumbala*	Alkaline, sticky
Japan, Korea, China	Soybean	*Shoyu*	Alkaline, liquid, seasoning
China, Taiwan	Soybean curd	*Sufu*	Mild-acidic, soft
Indonesia	Soybean	*Tauco*	Alkaline, paste, use as flavoring agent
Indonesia (Origin), The Netherlands, Japan, USA	Soybean	*Tempe*	Alkaline, solid, fried cake, breakfast
Thailand	Soybean	*Thua nao*	Alkaline, paste, dry, side dish
India	Soybean	*Tungrymbai*	Alkaline, sticky, curry, soup
Nigeria	African oil bean (*Pentaclethra macrophylla*)	*Ugba*	Alkaline, flat, glossy, brown in color
India	Black gram	*Wari*	Ball-like, brittle, side dish
China	Soybean	*Yandou*	Alkaline, sticky, salted, snack
E. Fermented Root Crop Foods			
Country	**Substrate**	**Product**	**Organoleptic characters and culinary**
Central Africa, Zaire	Cassava	*Chikwangue*	Solid state, staple
East and Central Africa	Cassava	*Cingwada*	Solid state
West Africa	Cassava	*Fufu*	Submerged, staple
West and Central Africa	Cassava	*Gari*	Solid state, staple
West Africa	Cassava	*Lafun/Konkonte*	Submerged, staple
Indonesia	Cassava	*Tapé*	Sweet dessert
Malaysia	Cassava, *Ragi*	*Tapai Ubi*	Sweet dessert
F. Fermented Meat Foods			
Country	**Substrate**	**Product**	**Organoleptic characters and culinary**
Portugal	Pork or beef, bread chopped fat, spices, salt	*Alheira*	Dry/semi-dry, sausage
Spain	Pork, coarse chopped, spices, salt	*Androlla*	Dry, pork sausage
India, Nepal	Large intestine of chevon	*Arjia*	Sausage, curry
India	Chevon	*Chartayshya*	Dried, smoked meat, curry
Spain	Pork	*Chorizo*	Dry, coarse chopped, spices, salt; sausage
Spain	Pork blood, onions, rice, bread or wheat flour	*Morcilla*	Black sausage, stews

(Continues)

TABLE 1 (Continued)

F. Fermented Meat Foods			
Country	**Substrate**	**Product**	**Organoleptic characters and culinary**
India	Yak, beef, pork, crushed garlic, ginger, salt	*Kargyong*	Sausage like meat product, curry
Thailand	Pork meat, pork skin, salt, rice, garlic	*Nham (Musom)*	Fermented pork
Vietnam	Pork, salt, cooked rice	*Nem-chua*	Fermented sausage
Turkey, Iraq	Chopped beef meat with lamb fat, heavily seasoned	*Pastirma*	Dry/semi-dry, sausage
Europe, America, Australia	Pork, beef	*Peperoni*	Dried meat, smoked, sausage
Thailand	Pork, rice, garlic, salt	*Sai-krok-prieo*	Fermented sausage
Spain	Pork or beef meat, fat, NaCl, spices	*Salchichon*	Dry, sausage
Italy	Chopped pork meat, spices, NaCl	*Salsiccia*	Dry/semi-dry, sausage
Italy	Chopped lean pork meat, NaCl and spices	*Soppressata*	Dry/semi-dry, sausage
Turkey	Chopped meat, pork or beef, curing salts and various spices	*Sucuk*	Dry, sausage
India	Goat, buffalo meat, turmeric powder, mustard oil, salt	*Suka ko masu*	Dried or smoked meat, curry
Philippines	Pork, salt, sugar, potassium nitrate	*Tocino*	Fermented cured pork
G. Fermented Fish Products			
Country	**Substrate/raw materials**	**Product**	**Organoleptic characters and culinary**
Philippines	Shrimp, rice, salt.	*Balao-balao (Burong Hipon Tagbilao)*	Fermented rice shrimp, condiment
Malaysia	Shrimp, salt	*Belacan (Blacan)*	Paste, condiment
Indonesia	Fish, shrimp	*Bakasang*	Paste, condiment
Philippines	Milkfish, rice, salt, vinegar	*Burong Bangus*	Fermented milkfish, sauce
Philippines	Fish, rice, salt	*Burong Isda*	Fermented fish, sauce
Thailand, Malayasia	Marine fishes, salt, sugar	*Budu*	Muslim sauce, fish sauce
India	Fish (*Schizothorax richardsonii*), salt, turmeric powder	*Gnuchi*	Eat as curry
Korea	Shell-fish	*Gulbi*	Salted and dried, side dish
India	Finger sized fish (*Esomus danricus*)	*Hentak*	Condiment
Thailand	Mussel (*Mytilus smaragdinus*), salt	*Hoi-malaeng pu-dong*	Fermented mussel
Japan	Squid, salt	*Ika-Shiokara*	Fermented squid
Korea	Fish	*Jeotkal*	High-salt fermented, staple

(Continues)

TABLE 1 (Continued)

G. Fermented Fish Products

Country	Substrate/raw materials	Product	Organoleptic characters and culinary
India	Fish (*Gudushia chapra, Pseudeutropius atherinoides, Cirrhinus reba*), salt	*Karati, Bordia, Lashim*	Dried, salted, side dish
Japan	Horse mackerel, salt	*Kusaya*	Fermented dried fish
Korea	Small sardine, salt	*Myulchijeot*	Fermented sardine
Japan	Sea water fish, cooked millet, salt	*Narezushi*	Fermented fish-rice
Thailand	*Solephorus* sp., *Ristelliger* sp. *Cirrhinus* sp., water, salt	*Nam pla (Nampla-dee, Nampla-sod)*	Fish sauce
India	Fish (*Puntius sophore*), salt	*Ngari*	Fermented fish
Vietnam	Marne fish	*Nuoc mam*	Fish sauce, condiment
Philippines, Indonesia	*Stolephorus* sp., *Clupea* sp., *Decapterus* sp., *Leionathus* sp., salt	*Patis*	Fish sauce
Thailand	Marine fish, red molds rice (*Ang-kak*), salt	*Pla-paeng-daeng*	Red fermented fish
Thailand	Marine fish, salt, boiled rice, garlic	*Pla-som (Pla-khao-sug)*	Fermented fish, condiment
Korea	Shrimp (*Acetes chinensis*), salt	*Saeoo Jeot (Jeotkal)*	Fermented shrimp
India, Bangladesh	*Puntis*	*Shidal*	Semi-fermented, unsalted product; 4-6 months fermentation; curry/pickle
Japan	Anchovy, opossum shrimp, salt	*Shottsuru*	Fish sauce, condiment
India	Fish (*Punitus sarana*)	*Sidra*	Dried fish, curry
Korea	Sea water fish, cooked millet, salt	*Sikhae*	Fermented fish-rice, sauce
India	River fish (*Schizothorax richardsoni*), salt, turmeric powder	*Suka ko maacha*	Smoked, dried, curry
India	Fish (*Harpodon nehereus*)	*Sukuti*	Pickle, soup and curry
Sweden	Fish	*Surströmming*	Fermented herrings
India	Fish	*Tungtap*	Fermented fish, paste, pickle

H. Alcoholic Beverages

Country	Substrate	Starter/Organisms	Beverage	Sensory property and nature
India, China (Tibet), Bhutan	Barley, millet	*Phab*	*Aarak*	Distilled from *chyang*, clear liquor
India	Rice	*Hamei*	*Atingba*	Mild-alcoholic, sweet-sour
India	Rice	*Phab*	*Apong*	Mild-alcoholic
Russia	Millet	LAB, Yeasts	*Bagni*	Liquid
South Africa	Sorghum, millet	LAB, Yeasts	*Bantu beer*	Opaque appearance, sour flavor
Philippines	Sugar cane	*Bubod, binubudan*	*Basi*	Clear or cloudy liquid
India, Nepal	Rice	*Marcha*	*Bhaati jaanr*	Mild-alcoholic, sweet-sour, paste

(Continues)

TABLE 1 (Continued)

H. Alcoholic Beverages				
Country	**Substrate**	**Starter/Organisms**	**Beverage**	**Sensory property and nature**
India	Maize-rice/barley	*Phab*	*Bhang-chyang*	Extract of *mingri*
World-wide	Fruit juice	*S. cerevisiae*	Brandy	Distillates of fermented fruit juices
Indonesia	Rice	*Ragi*	*Brem*	Dried, sweet-sour, mild alcoholic product
Egypt	Wheat, malt	LAB	*Bouza*	Alcoholic thin gruel
Bulgaria, Romania, Turkey, Albania	Wheat, rye, millet, maize	LAB, Yeasts	*Boza*	Cooked slurry
Kenya	Maize, sorghum, finger millet	Yeasts, LAB	*Bussa*	Alcoholic thin gruel
Uganda	Sorghum, millet	Yeasts, LAB	*Bushera*	Slurry
India	Barley	*Phab*	*Buza*	Thick liquor
Colombia	Maize	Yeasts	*Champus*	Mild-alcoholic beverage
France, Spain, Ireland, Slovenia	Apple	Yeasts	*Cider*	Clear alcoholic drink
China (Tibet), Bhutan, Nepal, India	Finger millet/barley	*Phab*	*Chyang/Chee*	Mild-alcoholic, slightly sweet-acidic
India	Apricot	Yeast	*Chulli*	Filtrate, clear
Mongolia	Millet	LAB, yeasts	*Darassun*	Liquid
India	Cereal	Yeast, LAB	*Daru*	Alcoholic beverages; filtrate
India	Red rice	Yeast, LAB	*Duizou*	Fermented rice beverage
India	Rice, paddy husk	Yeast, LAB	**Ennog**	Black rice beer
Korea	Rice	*Nuruk*	*Ewhaju*	Non-distilled, filtered and clarified, clear liquor
India, Nepal	Buck wheat	*Marcha*	*Faapar ko jaanr*	Mild-acidic, alcoholic
World-wide	Cashew apple	*S. cerevisiae*	*Feni*	Distilled wine from cashew apples, strong flavor
India, Nepal	Wheat	*Marcha*	*Gahoon ko jaanr*	Mild-acidic, alcoholic
World-wide	Maize, rye, barley	*S. cerevisiae*	Gin	Clear, high-alcohol distilled from fermented maze, flavored with juniper berries
Benin	Sorghum	Yeasts, LAB	*Gowé (Sifanu)*	Alcoholic, cooked slurry
India, Nepal	Barley	*Marcha*	*Jao ko jaanr*	Mild-acidic, alcoholic
India	Rice	Yeasts, LAB	**Jou**	Mild-alcoholic beverage
Zimbabwe	Wild fruit (*Ziziphus mauritiana)*	Yeasts, LAB	**Kachasu**	Distilled, high alcohol-content drink
South Africa	Sorghum, millet	LAB, Yeasts	**Kaffir beer (*same as* Bantu beer)**	Opaque appearance, sour flavor
India	Carrot/beet roots	*Torani* contains LAB, yeasts	*Kanji*	Strong flavored
Thailand	Rice	*Loogpang*	*Khao maak*	Juicy, white colored, sweet taste, mild alcoholic
India	Rice	*Thiat*	*Kiad lieh*	Distilled liquor, clear
Thailand	Rice	*Loogpang*	*Krachae*	Non-distilled and filtered liquor
India, Nepal	Finger millet	*Marcha*	*Kodo ko jaanr*	Mild-alcoholic, sweet-acidic
China	Rice	*Chiu yueh*	*Lao chao*	Sweet-sour, mild alcoholic paste
India	Maize-rice, barley	unknown	*Lohpani*	Alcoholic liquor
India, China (Tibet)	Barley	*Phab*	*Lugri*	Sweet-sour, mild alcoholic, thick liquid
India	Rice	Yeast, Mould	*Madhu*	Distilled liquor

(Continues)

TABLE 1 (Continued)

H. Alcoholic Beverages				
Country	**Substrate**	**Starter/Organisms**	**Beverage**	**Sensory property and nature**
Zimbabwe	Maize	Yeast, LAB	*Mangisi*	Liquor
India, Nepal	Maize	*Marcha*	*Makai ko jaanr*	Mild-alcoholic, sweet-sour
Tanzania	Malted millet	Yeast, LAB	*Mbege*	Acidic, mild-alcoholic
Sudan	Millet, cassava	Yeasts, LAB	*Merrisa*	Turbid drink
India	Maize-rice/barley	*Phab*	*Mingri*	Sweet, mild alcoholic, thick
Thailand	Rice	*Loogpang*	*Nam khao*	Distilled liquor
India	Coconut palm	Yeasts, LAB	*Nareli*	Sweet, milky, effervescent, mild alcoholic
India	Red rice	*Khekhrii*	*Nchiangne*	Distilled liquor
India	Rice-millet	*unknown*	**Oh**	Soft, mild-alcoholic beverage
Thailand	Rice	*Loogpang*	*Ou*	Distilled liquor
Palm-growing regions	Palm sap	Yeasts, LAB	Palm wine/*Toddy*	Sweet, milky, effervescent and mild alcoholic
Nepal	Rice	*Manapu*	*Poko*	Sweet-acidic, mild-alcoholic
India	Rice	Molds, Yeast, LAB	*Pona*	Mild-alcoholic, sweet-sour, paste
Mexico	Agave juice	Yeasts, LAB	*Pulque*	White, viscous, acidic-alcoholic
India, Nepal	Cereals	*Marcha*	*Raksi*	Clear distilled liquor
World-wide	Molasses	*S. cerevisiae*	***Rum***	Distilled liquor, clear
Vietnam	Rice	*Men*	**Ruou de**	Distilled liquor, clear
Vietnam	Rice	*Men*	**Ruou nep**	Distilled liquor, clear
Vietnam	Rice (purple)	*Men*	**Ruou nep than**	Non-distilled fermented rice, viscous, thick
Vietnam	Rice, maize, cassava	*Men*	**Ruou nep chan**	Non-distilled fermented rice, viscous, thick; or sometimes distilled
India	Rice	Yeasts	*Ruhi*	Distilled liquor
Japan	Rice	*Koji*	*Saké*	Non-distilled, clarified and filtered liquor
Thailand	Rice	*Loogpang*	*Sato*	Distilled liquor
Japan	Rice	*Koji*	*Shochu*	Distilled spirit
Japan	Sugar cane	*Koji*	*Shoto saké*	Liquor
India, Nepal	Cassava tuber	*Marcha*	*Simal tarul ko jaanr*	Mild-alcoholic, sweet-sour
India	Barley	Yeasts	*Sing sing*	Beverage
Korea	Rice	*Nuruk*	*Soju*	Distilled liquor
World-wide	Grapes	*S. cerevisiae*	Sparkling wine or Champagne	Clear and flavored
India	Finger millet	*Dhehli*	*Sura*	Alcoholic
Korea	Rice, wheat, barley, maize	*Nuruk*	*Takju*	Alcoholic
Philippines	Rice	*Bobod*	*Tapuy*	Sweet, sour, mild alcoholic
Malaysia	Rice	*Ragi* or *jui-piang*	*Tapai pulut*	Sweet, sour, mild alcoholic
Malaysia	Cassava	*Ragi* or *jui-piang*	*Tapai ubi*	Sweet, sour, mild alcoholic
Indonesia	Rice, cassava, maize, millet	*Ragi*	*Tapé- kekan*	Sweet-sour alcoholic paste
India	Date palm	Yeasts, LAB	*Tari*	Sweet, alcoholic beverage
Benin	Red sorghum	Yeast	*Tchoukoutou*	Effervescent, sweet
	Agave juice	Yeast	*Tequila*	Effervescent, sweet,
India	Finger millet, barley	Molds, Yeasts	*Themsing*	Mild-alcoholic, sweet

(Continues)

TABLE 1 (Continued)

H. Alcoholic Beverages				
Country	**Substrate**	**Starter/Organisms**	**Beverage**	**Sensory property and nature**
China, Taiwan	Rice	*Chiu-yueh*	*Tien-chiu-niang*	Mild-alcoholic, sweet
India	Palmyra and date palm sap	Yeasts, LAB	*Tari*	Sweet, milky, effervescent and mild alcoholic
East Africa	Maize	Yeasts, LAB	*Togwa*	Cooked slurry
Russia, Poland, Finland	Massed potato	*S. cerevisiae*	Vodka	Clear, distillate, flavored, high-alcohol content spirit
World-wide	Barley	*S. cerevisiae*	Whisky	Distillate clear liquor from fermented malted barley
World-wide	Grapes	Yeasts	Wine	Red, white, flavored, clear
Korea	Rice, wheat, barley, maize	*Nuruk*	*Yakju*	Alcoholic
India	Rice	*Hamei*	*Yu*	Distilled from *atingba*, clear
India	Rice	Yeasts, LAB	*Zu*	Distilled from fermented rice; clear liquor
India	Rice	*Khekhrii*	*Zutho/Zhuchu*	Milky white, sweet-sour, mild-alcoholic

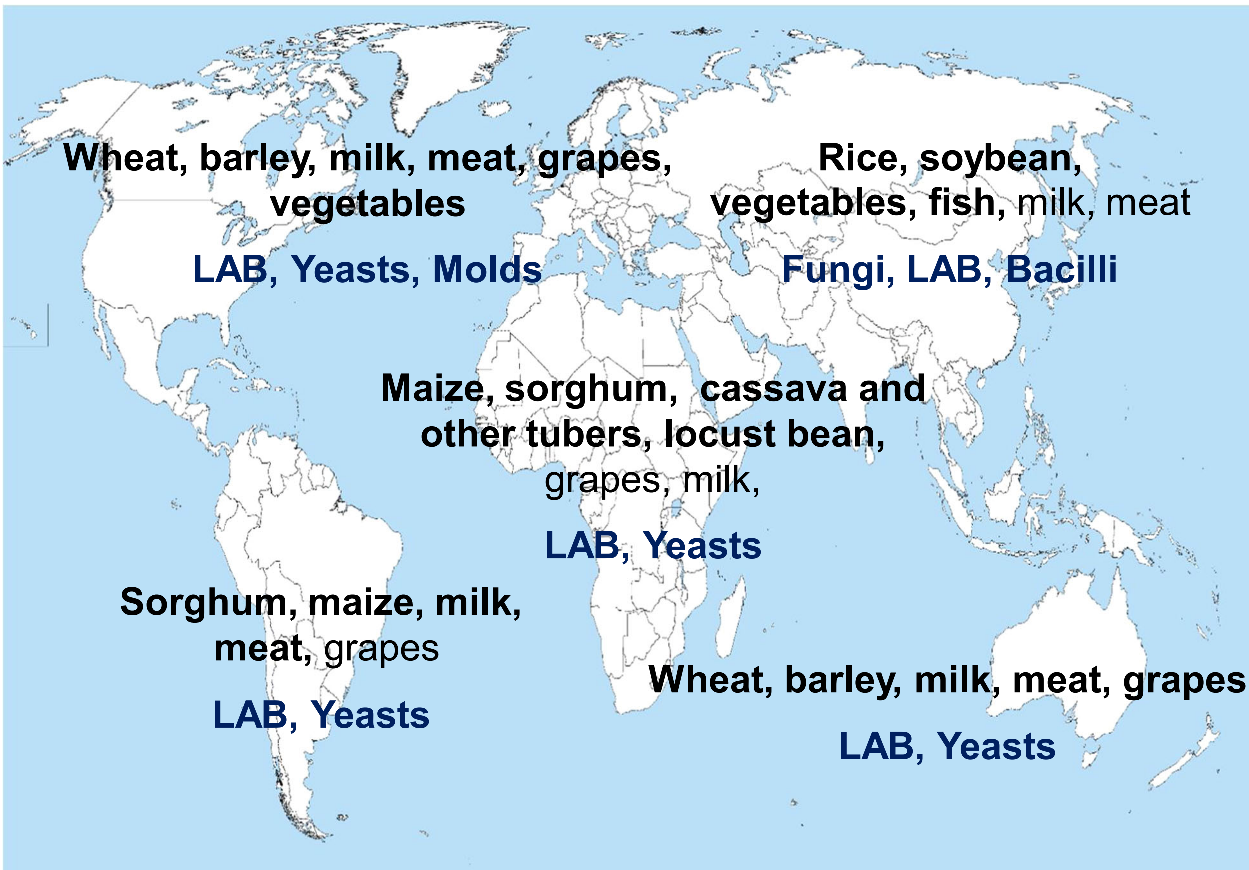

FIGURE 1 Global reach of fermented foods and beverages and the substrates and major groups of microbes involved in their manufacture. The main substrates are indicated in bold. Adopted from Tamang and Samuel 2010.

produced at home and rely on these traditional fermentation methods (Tamang, Holzapfel, & Watanabe, 2016a). However, starter cultures became available in the 20th century, and they are now commonly used in industrial fermentations, including wine (Berbegal, Spano, & Fragasso, 2018), dairy (Mayo, Ammor, Delgado, & Alegría, 2010), and meat (Laranjo, Elias, & Fraqueza, 2017), especially in the West.

3 | THE ORIGINS OF FERMENTED FOODS AND BEVERAGES

3.1 | Vegetables

Despite the substantial geographical and cultural differences in how fermented foods and beverages are produced and consumed, their history is similar across continents and regions. Descriptions of vegetable fermentations date back to the Song dynasty (960 to 1279 CE) in China (Tamang & Samuel, 2010). Likewise, technology for making kimchi was documented in the first century CE (Chang, 1975). Similarly, methods of preservation of olives through fermentation was recorded in ancient Rome at nearly the same time (Sealey & Tyers, 1989). Fermentation of cabbage likely occurred around the same time, although methods for preparation of sauerkraut were not described until the 17th century CE (Pederson & Albury, 1969).

3.2 | Cereals and breads

Tools, pottery, and other archaeological findings provide evidence that breads were produced in ancient Egypt during 10,000 BCE (Samuel, 2002). "Dosa," an ethnic fermented food of India, prepared from rice and black gram was recorded in the Tamil literature in the first century (Achaya 2003). Preparation of methods of "idli," a fermented rice and black gram food of India and Sri Lanka, was mentioned in Kannada literature in 920 CE (Krishna Jois, 1969). Consumption of "dhokla," a popular fermented food of Western India prepared by mixture of wheat and Bengal gram was recorded around 1066 CE (Prajapati & Nair, 2003). Similarly, "jalebi," a popular fermented cereal product of India, Nepal, and Pakistan, which is crispy sweet, doughnut-like, and deep-fried was recorded around 1450 CE (Gode, 1943).

3.3 | Fermented soybean products

Wild soybeans were first cultivated in Northern China, and spread to the Center and South China regions, Southeast Asia and the Korean peninsula. They eventually reached Japan by 7 CE (Choi, 2009, Hymowitz, 1970). Fermented soybean products followed a similar path. Probably "natto," a sticky fermented soybean food of Japan was brought by Buddhist monks from China around 710 to 794 CE during Nara period (Ito, Tong, & Li, 1996, Kiuchi, 2001). The preparation and consumption of soy sauce and fermented soybean paste were first recorded in China during the Han dynasty around 2,200 years ago (Huang, 2000). Production methods of these products eventually reached Japan around 600 CE, where they became known as shoyu and miso (Yokotsuka, 1985). "Tempeh," a popular fermented soybean product originated on the island of Java in the 1600s and then spread to Indonesia (Shurtleff & Aoyagi, 2010).

3.4 | Fermented dairy products

"Dahi," a yoghurt-like fermented milk product of India, was mentioned in about 6000 to 4000 BCE in the Rig Veda and Upanishad, ancient sacred books of the Hindus (Yegna Narayan Aiyar, 1953). Likewise, the Turkish people in Asia also made a similar product, giving it the name "yoghurut" (Rasic & Kurmann, 1978). Evidence of production and consumption of cheese in Kujawy of Poland was recorded around 5500 BCE (Salque et al., 2012).

3.5 | Fermented fish products

The probable origin of fermented fish products in South East Asia appears to have occurred in the Mekong basins around 200 BCE to 200 CE (Ishige, 1993, Ruddle, 1993). Likewise, Thai-Lao, Burmese, and Khmer are believed to be the first ethnic groups of people to develop fermentation of freshwater fish products (Ishige, 1986). In Europe, two types of fish sauces, "garum" and "muria" originated in Greece (Tamang & Samuel, 2010). Records for preparation of fish sauces suggest their use during the pre-Roman period (fourth century BCE), primarily as a condiment (Badham, 1854; Curtis, 2001; Wilkins & Hill, 2006).

3.6 | Fermented meats

The preparation and consumption of fresh, cured, and fermented meat products have been a part of deep-rooted culture in Europe for thousands of years. Historically the Babylonians used to prepare sausages by stuffing minced animal flesh in intestines around 1500 BCE (Pederson, 1979). "Salami" might have originated from Salamis located on East coast of Cyprus (Lücke, 1988). Manufacture of sausage-like products spread during the Roman era throughout southern Europe and other areas near the Mediterranean Sea (Hutkins, 2019). In the east, at around the same time similar products appeared in Asia. Whether these early sausage products were actually fermented or not is not clear, but given the warm ambient temperatures, it is likely that fermentation had occurred.

3.7 | Alcoholic beverages

Beer appears to have originated in ancient Egypt and Mesopotamia around 4000 BCE (Damerow, 2012). Similar fermented beverages appeared in 2000 BCE in Mexico and also in Sudan in 1500 BCE (Tamang & Samuel, 2010). In general, these dates are based on archaeological and chemical studies of recovered remnants from various sites. Similar evidence recovered from archaeological sites in Iran suggests wine-making may have occurred even earlier, around 6000 BCE (Renfrew, 1999, Wilson, 1999). "Pulque," a South American-made alcoholic beverage, was inherited from the Aztecs 1,000 years ago (Goncalves de Lima, 1975).

TABLE 2 Fermented foods from past to present[a]

Traditional	Modern
Small scale (craft industry)	Large scale (in factories)
Vat, tanks exposed and open, often in wood	Vat, tanks enclosed and aseptic, often in stainless steel
Leaves and straw as wrapping materials	Plastics, other clean barriers for packaging
Manual	Automated
Variable fermentation times	Consistent and predictable fermentation times
Varying quality	Consistent quality
Safety and hygiene less appreciated	Safety and hygiene a major concern
No culture knowledge	Extensive culture knowledge

[a]Adapted from Hutkins 2019. Note these properties or conditions are not intended to reflect the entirety of the fermented foods industry, but rather the general manufacturing operations that exist.

Alcoholic products from India have been dated to 300 to 75 BCE (Prakash, 1961).

3.8 | From antiquity to modernization

The origins of fermented foods and beverages almost certainly began as inadvertent accidents. Microbial contamination of fresh raw materials would have been common 10,000 years ago, with spoilage a frequent and normal occurrence. On occasion, a more favorable outcome would have occurred, resulting in pleasant-tasting, intoxicating, and long-lasting products. Presumably, these accidental events would have been repeated enough times for observers to note the conditions that led to these positive outcomes. Nonetheless, it likely would have taken many centuries before humans would have learned how to control fermentation conditions to ensure consistency, safety, and quality. Eventually, the manufacture of fermented foods and beverages became industrialized, albeit on a very small scale. In the absence of science and microbiology, skilled crafts-persons were mainly responsible for developing the technologies for making fermented foods.

The historical records also indicate that the practices and technologies for manufacture of fermented foods evolved independently on every hemisphere. As humans migrated from region to region, food cultures and production practices did as well. Likewise, as civilizations were formed 5,000 years ago, along with armies and cities, there was greater demand for food, including fermented foods that were well-preserved foods. Thus, bread and beer were among the first mass-produced products, manufactured by Egyptian bakeries and Babylonian breweries around 3000 BCE to 4000 BCE.

At very near the same time, techniques for food and beverage fermentation also evolved in the eastern hemisphere. Skilled artisans developed small-scale technologies that also grew in size, for many of the same reasons as in the west. Although the dietary preferences and culinary practices in India, China, Japan, and the Far East were quite different from those in the Mediterranean regions of the west, fermented foods, and beverages were still a prominent part. However, rather than milk, meat, and other animal products, plants, legumes, and seafood more frequently served as the main raw materials.

Remarkably, for most of modern human history, the most commonly consumed fermented foods and beverages had their origins long before there was any awareness of microbiology, biochemistry, or aseptic technique (Table 2). Thus, in much of the world, fermented products are still made in homes and villages using traditional techniques without the benefit of science. Vats are often open and exposed, aseptic practices are rarely observed, and manufacture is dependent on manual labor.

However, for large scale production, most of these practices are no longer applied. Indeed, as for other types of food processing, modernization of fermented foods manufacture has become global. Thus, production of most fermented foods and alcoholic beverages, whether conducted in a cheese plant in North America, a winery in France, or a shoyu factory in Japan, require thorough knowledge of science and technology. Starter cultures are commonly used, and many of the strains are well characterized, often with sequenced genomes. While product safety and quality are paramount, predictability, and consistency are also important. Advances in molecular biology, metabolomics, and bioprocessing also provide for new opportunities to address long-standing challenges. Examples include enhanced flavor production, improved shelf-life and preservation, and defense against bacteriophage.

4 | FROM MANUFACTURE TO MICROBIOTA: THE EVOLUTION OF FERMENTED FOODS AND BEVERAGES

4.1 | Fermented milk products from East and West

Where ever fresh milk has been used for food, fermented versions inevitably were produced and consumed. Although the time and place in which dairy husbandry was first practised are unknown, the nutritive nature of milk provided considerable advantages during human evolution. However, the same constituents in milk that make it nutritious also make milk highly perishable. Thus, fermentation evolved as the major way to preserve milk and its nutrients.

The spontaneous fermentation of milk is mediated by LAB that consumes lactose and produce lactic acid (Carr, Chill, & Maida, 2002). The most common dairy LAB includes species from four main genera: *Lactococcus, Lactobacillus, Leuconostoc,* and *Pediococcus*. In addition to forming lactic acid, these bacteria also modify other constituents of milk resulting in increased bioavailability of nutrients and enhanced quality (Smit, Smit, & Engels, 2005). Importantly, LAB and their metabolic products inhibit spoilage and pathogenic microorganisms (Arqués, Rodríguez, Langa, Landete, & Medina, 2015).

In much of the world, the spontaneous fermentation of milk has been largely displaced by induced fermentations mediated by starter cultures (Parente and Cogan, 2004). Dairy cultures consist of selected and well-defined strains of LAB species that are produced in concentrated and stable forms (Bintsis, 2018). Their wide availability, ease of use, and consistent properties have made them common even in developing countries.

Cow's milk is the basis for most dairy fermented products around the world. Still, milk from other mammals, including sheep, goat, camel, mare, buffalo, and yak may have been historically more important and remain so in certain regions. South European countries as well as many Asian, African, and other Mediterranean countries have centuries of tradition in small ruminant farming, such as ewes and goats. For example, most ewe's and goat's milk is used for the manufacture of traditional dairy products, mainly cheeses. Likewise, milk and fermented milk products of domesticated animals such as yak are common dairy commodities in the Himalayas and neighboring regions (Rai, Shangpliang, & Tamang, 2016). Milk of the various mammal species differs in chemical composition, including significant differences in parameters such as total solids, lactose, fat, protein, and mineral content. The diversity of fermented milk products is influenced, in part, by the use of milk from different animal species, but also by the wide variety of manufacturing practices (Figure 2). The latter affects the physical, chemical, sensory, and nutritional properties of the product. Processing conditions and product composition also pose strong selection pressure on the microorganisms that survive during manufacturing, ripening, and storage.

There are a large number of varieties of traditional and commercial fermented milk products with more than 400 generic names worldwide (Robinson & Tamime, 2006). There are at least another 1,000 varieties of cheese and cheese-like products that also exist (Kosikowski and Mistry 1997). Fermented dairy foods can be distinguished based on several factors, including mode of coagulation (enzyme or acid or acid plus heat); the means by which whey separation occurs (from none to complete); or by the nature of fermentation (lactic acid bacteria alone or lactic acid bacteria plus fungal or other adjunct cultures).

4.2 | Yoghurt and other cultured dairy products

The role of fermented dairy products in the diet of humans varies considerably, depending on provenance, culture, religion, and ethnicity. For example, tropical countries have generally not adopted pastoral farming, and milk products are not regularly consumed. In contrast, in more Northern regions (in both the West and East), dairy agriculture is common, and far more milk and dairy products are consumed. Naturally fermented milks, made without the benefit of a starter culture, are the simplest and probably the oldest type of fermented milk product produced around the world (Mayo et al., 2010). These so-called spontaneous fermentations rely on the microbes present in the raw material or on colonizers from the environment, including workers, animals, or equipment (Franz et al., 2014). Such products are still found in many countries and regions, such as "kad," "rayeb," "lben," "laban," "zabady," and "zeer" of Northern African and Middle East, "ergo" of Ethiopia, "roub" of Sudan, "amasi" of Zimbabwe, and "filmjölk" and "långfil" of Sweden (Tamang et al., 2016a).

Fermented milks made by inoculation of a starter culture have become widespread, and of these, yoghurt and yoghurt-related products are the most common. Although commercial cultures are now available globally, for many traditionally produced products, the culture is derived from a previous batch (i.e., back-slopping). Examples include "zabady" from Egypt (El-Baradei, Delacroix-Buchet, & Ogier, 2008) and "dahi" from India, Nepal, Bhutan, and Bangladesh (Dewan & Tamang, 2007), "chhurpi," "chhu," "churkam," "dahi, "gee," and "mar" of India (Dewan & Tamang, 2006; Shangpliang, Rai, Keisam, Jeyaram, & Tamang, 2018).

Prior to the latter half of the 20th century, the preparation and consumption of yoghurt or yoghurt-like products were originally confined to people residing in Europe, the Balkans, Middle East, and India (Kosikowski & Mistry 1997). Today, yoghurt is considered the most commercially important and widely consumed fermented milk around the world.

In traditional yoghurt production, milk (usually from cows, but also goat, sheep, and others) is brought to a boil or near boil, then cooled and inoculated. However, because the yoghurt microbes, *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*, are moderate thermophiles and require warmer temperatures (40 to 45 °C) for fermentation (Lick, Drescher, & Heller, 2001), the manufacturing conditions must accommodate this requirement. Thus,

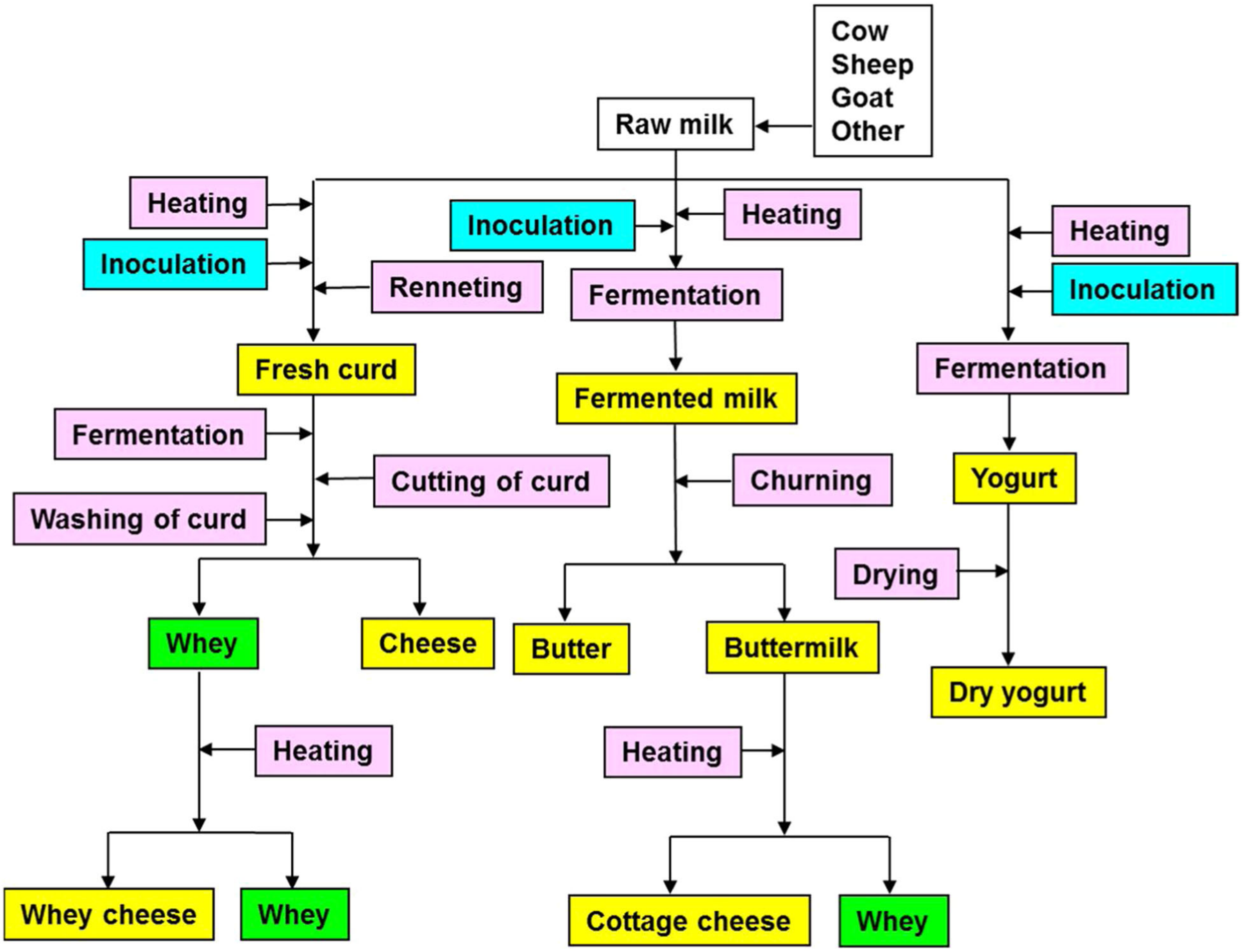

FIGURE 2 Generalized flow chart for manufacture of fermented dairy products. Milk, the starting material, can be obtained from several main animals. Technological processes, shown in pink, include fermentation, as well as optional heating steps and curd-handling steps. Inoculation, shown in light blue, is usually done with pure cultures but back-slopping is still a common practice. Finished products, shown in yellow, include a wide range of cheese and cultured products, along with whey, shown in green.

in the absence of temperature-controlled incubators, traditional producers must rely on warm ambient temperatures, direct exposure to sunlight, or proximity to cooking areas.

Other traditional fermented milks include Bulgarian buttermilk, "kefir," "koumis," and "viili" (de Ramesh, White, Kilara, & Hui, 2006). Bulgarian buttermilk is made via fermentation by *L. delbrueckii* subsp. *bulgaricus*, a prolific acid-producer (producing up to 4% lactic acid), resulting in significantly more tartness than yoghurt. "Kefir" is a viscous, acidic, slightly effervescent, and mildly alcoholic milk beverage produced by spontaneous fermentation of milk with kefir grains (Ahmed et al., 2013). The latter consist of a polysaccharide matrix in which a stable microbial community is maintained. Lactic acid bacteria, acetic acid bacteria, and yeast coexist in these grains, and after fermentation, the grains can be recovered and reused (Prado et al., 2015). Kefir appears to have originated in the Balkan–Caucasian region, but more recently, its consumption has extended through the world (Ahmed et al., 2013).

"Koumis" is another naturally fermented milk product from the Caucasian area. Similar products such as "chigee" and "airag" are produced in Mongolia and north western China, (Watanabe et al., 2009). "Koumis" is defined by the use of mare's milk, which because of its lower protein and higher fat content, gives the product a smooth, rich taste. "Viili" is a very popular, naturally fermented milk product of Finland that contains lactic acid bacteria as well as the filamentous yeast *Geotrichum candidum*. Similar products are also made in Sweden, Norway, Denmark, and Iceland (Tamime & Robinson, 2007). Most of these products share a thick and sticky consistency due to the development of extracellular polysaccharide (EPS)-producing strains of *Lactococcus lactis* (Toba, Kotani, & Adachi, 1991).

4.3 | Cheese

Coagulated milk gels are stable if left undisturbed, but if they are accidentally or intentionally broken, curd and whey separates. Cheese results from the removal of whey, giving a product that can be consumed fresh or stored for long periods if properly salted and/or dehydrated. Acid-coagulated cheeses (Cottage cheese, Cream cheese, Quarg) account for about 25% of cheese consumption; a small amount is also made by acid plus heat (Ricotta). The rest is made by enzymatic coagulation via rennet, pure or engineered chymosin, or other acid-proteinases.

Based on the characteristic mode of manufacture, nature of ripening, or moisture content, cheeses can be classified into several major families: soft-to-hard bacterially ripened internally, bacterial surface-ripened, and mould-ripened (Fox et al. 2000; Law, 1999). Internal bacterially ripened cheeses include very-hard (Parmesan), hard (Cheddar), cheese with eyes (Emmental), Dutch-types (Edam and Gouda). Heavily salted cheeses (Feta) and "pasta filata" varieties (Mozzarella) may be included in this group, although they are generally not ripened. The surface-ripened cheese group includes Limburger, Munster, and Tilsit. Mould-ripened varieties include those with fungi on the surface (Brie, Camembert) and those with internal fungi (Roquefort, Gorgonzola, Stilton, Cabrales).

Most of these cheeses are now produced worldwide, although they are often associated with particular regions or countries. Indeed, the names of several of these cheeses are also protected by country-of-origin types of labels, which also require they be manufactured according to traditional procedures. For many centuries, the countries that consumed the most cheese were located in Europe and North America. While this remains the case on a per capita basis, in just the past decade, Asian countries (mainly China) have become large consumers (and importers) of cheese as well as other fermented dairy products (OECD, 2018).

Variations in the type of milk, microbes, and technologies used in the fermentation of fermented milk have led to an extraordinary assortment of traditional fermented milk products. This diversity is represented from East to West and reflects human history from ancient times to the present. Although many of these products are currently manufactured in modern factories on an industrial scale using well-defined cultures, others are still produced locally on a small scale, without the benefit of any scientific or technological knowledge. Nonetheless, they all constitute an important part of the diet and cuisine. Importantly, they also contribute to local and national economies.

4.4 | Fermented meat products

Animal flesh is consumed all over the world. Exceptions include regions in India and Asia, where a majority of Hindu and many Buddhists exclude meat from their diet due to religion taboos (Tamang & Samuel, 2010). Whole pieces or slices of meats of various domesticated animals are traditionally preserved by smoking/sun-drying or other means of drying. Some meat is stuffed into animal intestine to make sausages, and many of these products are fermented to enhance organoleptic and preservation properties (Plavsic, Okanovic, Gubic, & Njezic, 2015; Rantsiou & Cocolin, 2008; Tamang et al., 2016a; Zakpaa, Imbeah, & Mak-Mensah, 2009). Indeed, stuffing of comminuted, diced, or chopped meats inside casing material (usually animal intestines), followed by fermentation, is one of the most popular forms by which processed meat products are consumed in the West (Adams, 2010; Franciosa, Alessandria, Dolci, Rantsiou, & Cocolin, 2018).

The dominant microbial groups present in meat fermentations are now known. The main group are the lactic acid bacteria (Bartkiene et al., 2019; Khanh, May, Smooker, Van, & Coloe, 2011; Nguyen et al., 2013), including strains of *Lactobacillus sakei, Lb. curvatus, Lb. plantarum, Pediococcus pentosaceus, Enterococcus faecium, Leuc. carnosum*, *Leuc. gelidum, Leuc. pseudomesenteroides, and Weissella* (Dias, Santos, & Schwan, 2015; Laranjo et al., 2017). The other main group of bacteria are the *Kocuria*, micrococci, and coagulase-negative staphylococci (Marty, Buchs, Eugster-Meier, Lacroix, & Meile, 2011; Sánchez, Stavropoulou, & Leroy, 2017). In particular, these microbes reduce nitrate to nitrite and also contribute flavors in fermented sausages (Lücke, 2003; Sánchez et al., 2017). On occasion, *Enterobacteriaceae* may also be present. Several species of yeasts and molds (Encinas, Lopez-Diaz, Garcia-Lopez, Otero, & Moreno, 2000; Tamang & Fleet, 2009) also play important roles in ripening of fermented meats, especially for flavor and texture development (Lücke, 2015).

4.5 | Fermented root and tuber products

In Africa, the roots of raw cassava (*Manihot esculenta*) are naturally fermented into a variety of edible food products, including "gari," "kocho," "fufu," "foo foo," "chikawgue," and so on. (Franz et al., 2014). These are primarily spontaneous fermentations with lactic acid bacteria, although other microbes may also be involved. For example, *Corynebacterium manihot* dominates the initial stage of cassava fermentation (Oyewole, Olatunji, & Odunfa, 2004), followed by several species of lactic acid bacteria including *Lb. acidophilus*, *Lb. casei, Lb. fermentum,* and *Lb. plantarum* (Oguntoyinbo & Dodd, 2010). The roots of cassava can also be fermented into sweet dessert products. One such product, called "tape" (or "tapai") is popular in Indonesia and Malaysia (Surono, 2016). Unlike in Africa, for tape production, the cassava roots are not fermented naturally, but rather are fermented using a dry starter culture called "ragi" that consists of bacteria, yeast, and mold. Products based on fermentation of root and tubers are rarely observed in the American and European food culture.

4.6 | Fermented fish and other seafood products

Fish and seafood are highly perishable; hence, several simple technologies have been adopted for long shelf-life and preservation. These include smoking, salting, curing, drying, and fermentation. In addition to their preservation properties, these products enhance flavor and contribute "deliciousness" (Salampessy, Kailasapathy, & Thapa, 2010).

Fermented fish products generally consist of two types. Fish can be mixed with salt (15% to 25%) to create fish sauces and fish pastes; these are among the most widely consumed condiment and flavoring agents in many parts of Asia. In contrast, mixtures of fish, salt, and carbohydrate can be prepared yielding products such as "pla ra" of Thailand and "burong isda" of Philippines (Adams, 1998).

In Asia, fish fermentation technology is a traditional technique, and many of the products are prepared at home. They are regularly consumed as side-dishes and flavor-enhancing condiments. Many of these products are region-specific and include "patis" of Philippines, "nam pla" and "pla ra" of Thailand, "shottsuru," bonito flakes, "izushi" (fermented sushi), and "shiokara" of Japan, "jeot kal" of Korea, "pindang" of Indonesia, "budu" of Malaysia, "nga pi" of Myanmar, and "sukuti" and "sidra" of India and Nepal, "ngari," "hentak," "tungtak," and "shidal" of India, "yucha" of China, "mehiawah" of Middle East Asia (Al-Jedah, Ali, & Robinson, 1999; Devi, Deka, & Jeyaram, 2015; Hwanhlem et al., 2011; Kobayashi, Kimura, & Fujii, 2000a; Muzaddadi & Basu, 2012; Saithong, Panthavee, Boonyaratanakornkit, & Sikkhamondhol, 2010; Thapa, Pal, & Tamang, 2004, 2006, 2007; Wu, Kimura, & Fujii, 2000; Zhang et al., 2016).

Although fish sauces are widely used as a condiment throughout East Asia, they are most commonly associated with Thailand, Vietnam, Laos, Malaysia, Myanmar, Cambodia, and other South Asian regions (Tamang et al., 2016a; Thongthai & Gildberg, 2005). In contrast, sauces prepared from fermented soybean paste are more commonly used in Japan, Korea, and China (see below). Microbiology of fermented fish sauces have been studied for more than 30 years, and several species of lactic acid bacteria, micrococci, bacilli, and some species of yeasts have been reported (Watanaputi, Chanyavongse, Tubplean, Tanasuphavatana, & Srimahasongkhraam, 1983; Tanasupawat et al., 1991; Kobayashi, Kimura, & Fujii, 2000b; Thapa et al., 2004; Thongthai & Suntinanalert 1991; Tyn, 1993; Wu et al., 2000).

4.7 | Fermented legumes

The primary legume used to produce fermented foods is soybeans. These products constitute a major component of the Asian culture, diet, and cuisine. Other beans, including black grams and locust beans are more common in the Indian subcontinent and Africa, respectively. Based on the ethnic and culinary practices of the local or regional populations, three general types of fermented soybean foods are produced in Asia. The main type is those fermented by filamentous fungi, yeast, and lactic acid bacteria that yield salty sauces (e.g., soy sauce, "shoyu," "tamari") and pastes (e.g., "miso").

Another type is those fermented by bacteria, mainly *Bacillus* spp. (Tamang et al., 2016a; Zhang, Tatsumi, Fan, & Li, 2007). These consist of whole beans that become sticky, sweet, and slightly ammoniacal. Their manufacture and consumption are generally restricted to a few Asian countries, the so-called "natto triangle" (Nakao, 1972). The primary species associated with these fermentations is *Bacillus subtilis* var *natto*. This organism is responsible for several functional properties, including the formation of the sticky polymer and sweet flavor that are characteristic of natto (Meerak et al., 2007; Kamada et al., 2014; Tamang, 2015). Because this organism and natto-like products are more widespread that originally reported, the "natto-triangle" was retermed as the "*Kinema-Natto-Thua* (KNT) triangle" (Tamang, 2010b). Indeed, *natto*-producing strains are highly clonal, based on plasmid distribution profiles (Hara, Zhang, & Ueda, 1983, 1986, 1995) and 16S rRNA gene sequencing of *Bacillus* species from "kinema," "natto" and "chungkokjang," which showed >99% similarity (Tamang et al., 2002). The "KNT-triangle" includes Eastern Nepal, North East regions of India and Bhutan (kinema and similar products), Myanmar ("pepoke"), Northern Thailand ("thua nao"), Laos ("sieng"), South China ("douchi"), Korea (chungkokjang), and Japan (natto) (Tamang, 2010b, 2015). Interestingly, the preparation and consumption of *Bacillus*-fermented sticky non-salty soybean foods are confined only within these few countries; no such product has been reported from any other parts of the world.

A third type of fermented soybean is tempeh, a *Rhizopus* mold-fermented soybean food, that originated in Indonesia, but that spread to the Netherlands (following Dutch colonization) and later the UK and North America (Shurtleff & Aoyagi, 2010).

In Africa, wild locust beans are naturally fermented into various foods used as condiments such as "dawadawa," "bikalga," "iru," "okpehe," "soumbala," and "dugba" of Africa (Franz et al., 2014; Olasupo, Odunfa, & Obayori, 2010). Many species of bacteria, but mostly *Bacillus* and lactic acid bacteria have been isolated from African-fermented legume products (Amoa-Awua, Terlabie, & Sakyi-Dawson, 2006, Azokpota, Hounhouigan, & Nago, 2006, Meerak et al., 2008, Ouoba, Cantor, Diawara, Traoré, & Jakobsen, 2003a, 2003b, 2004, 2005, 2007a, 2007b, 2008, 2010; Franz et al., 2014).

Fermented soybeans have been widely studied for the health benefits they may provide to consumers (Tamang, Shin, Jung, & Chae, 2016b). For example, regular consumption of chungkokjang may improve the glucose response in diabetic individuals, due to an increase in insulin resistivity (Shin, Kwon, M.Jeon, & Choi, 2011; Tolhurst et al., 2012). Consumption of natto has been reported to help or prevent osteoporosis, due to the rich content of vitamin K_2 that stimulates bone formation (Yanagisawa & Sumi, 2005).

4.8 | Fermented vegetables

Fermented vegetables are widely consumed as side dishes or as ingredients for several dishes in Eastern and Western countries. The major fermented vegetables in Western countries are table olives and sauerkraut. In contrast, in the East, each country or region produces and consumes their own unique fermented vegetables. These fermented products are mainly fermented by LAB, and thus they are often considered as possible sources of probiotic-like microbes. Accordingly, consumer interest in fermented vegetables containing live microbes has led to greater development and distribution of fresh and unheated products. The vegetable microbiota, cultures, technology, and health aspects of fermented vegetables are reviewed below.

Table olives have long been important nutritionally and economically, as well as for culinary traditions in most of the Mediterranean countries. Fermented olives are made from both alkaline- or brine-treated raw olives. In general, three main types are produced: Spanish-style green olives, California-style oxidized black olives, and Greek-style natural black olives (Heperkan, 2013; Rejano, Montaño, Casado, Sánchez, & de Castro, 2010). All rely on the authochthonous or indigenous microbiota for fermentation, with lactic acid bacteria (LAB) and yeasts as the primary organisms. LAB found in olives belong predominantly to such species as *Lactobacillus plantarum, Lb. casei, Leuconostoc mesenteroides*, and *Pediococcus pentosaceus* while yeasts include chiefly *Pichia membranaefaciens*, *P. fermentans, Saccharomyces cerevisiae, Candida oleophila, Candida silvae*, and *Cystofilobasidium capitatum* (Peres, Peres, Hernández-Mendoza, & Malcata, 2012).

Lactic acid bacteria play the most important role in fermentation of olives by converting fermentable sugars to lactic acid and other organic acids depending on their metabolic pathways and yeasts also contribute organoleptic properties (Aponte et al., 2010; Arroyo-López et al., 2012). Fermented olives contain many several nutrients and bioactive compounds, including polyphenolic antioxidants. Olives are a major component of the Mediterranean diet and their consumption is associated with low incidence of cardiovascular diseases and cancer (Boskou, 2008).

Cabbage is another widely consumed vegetable in both the East and West, with fermented versions popular in many regions. In western countries, where fermented cabbage is more commonly known as sauerkraut, the starting material is European or white cabbage (*Brassica oleracea*). Sauerkraut is produced in many European countries, as well as the United States, using very similar production methods. Outer leaves are removed, the cabbage is shredded and mixed with salting, filled into tanks, covered, and allowed to fermentation for days or weeks. The final product can be packaged and pasteurized or left unheated and distributed fresh. Only the latter would contain live microbes.

In addition to development of the brine and enhancing flavor, salt has an important microbiological role. Addition of salt limits growth of undesirable microorganisms such as *Pseudomonas*, *Flavobacterium*, coliforms, and various fungi, and provides selection for LAB. The growth sequence of spontaneous fermentation is initiated by *Leuc. mesenteroides* followed by heterofermentative lactobacilli and finally by homofermentative lactobacilli (Pederson, 1979). Although species involved in the fermentation vary based on location, *Leuc. mesenteroides* and *Lb. plantarum* are usually among the major species. The use of starter cultures has been studied during sauerkraut fermentation for the purposes including increase levels of health beneficial compounds and reduction in salt concentration (Beganović et al., 2011, 2014).

Eastern countries produce a wide variety of their own fermented vegetables. Most are made using napa cabbage, radishes, cucumbers, beets, turnips, cauliflower, celery, and carrots. The representative fermented vegetables are kimchi in Korea, "pao-tsai" and "suan-tsai" in China and Taiwan, "nukaduke" and "sunki" in Japan, "gundruk," "sinki," "mesu," "soibum," and "soidon" in India and Nepal, "pak-gard-dong" and "noa-mai-dong" in Thailand, "sayur asin" in Indonesia, and "burong mustala" in the Philippines (Tamang et al., 2016a). All of these products are made by LAB, with *Lactobacillus* spp., *Leuconostoc* spp., *Pediococcus* spp., and *Weissella* spp. as the major species involved in the fermentation (Tamang et al., 2005, 2008, 2009). Lactate and acetate production lowers pH and controls growth of spoilage microorganisms in the products. Metabolism by LAB may also result in formation of bioactive compounds, including antioxidants formed from phenolic compounds and bioactive peptides formed by proteolysis.

Among various vegetables, napa cabbage (*Brassica rapa*) is widely used in East Asian cuisine, especially for the manufacture of *kimchi*. *Kimchi* is a traditional Korean fermented vegetable made by fermenting salted napa cabbage, radish, and cucumber, with various spices, including red pepper powder, garlic, ginger, and other ingredients (Jang, Chung, Yang, Kim, & Kwon, 2015). As for other fermented vegetables, kimchi is made by a spontaneous fermentation.

Since the early 2000s, *Leuc. mesenteroides, Leuc. citreum,* or *Lb. plantarum* have been used as starter cultures in the *kimchi* industries (Lee et al., 2015) for achieving better and constant organoleptic quality. The use of pure cultures on a daily basis might be expected to promote proliferation of bacteriophage, with subsequent effects on the fermentation (similar to that which occurs in dairy fermentations). Although bacteriophages do exist for microbes found in fermented vegetables, they have not been considered to be problematic (Barrangou, Yoon, Breidt, Fleming, & Klaenhammer, 2002). More recently, however, it has been suggested that bacteriophages may indeed influence the growth, viability, and population dynamics of lactic acid bacteria during kimchi production (Jung et al., 2011; Kong & Park, 2019).

4.9 | Alcoholic beverages

Ethanol-containing fermented beverages are among the most economically and culturally important fermented food product. Their consumption, on a global basis, is associated with many culturally accepted practices, including rituals, customs, religions, and entertainment. Alcoholic products are produced and consumed on every continent and region, including beers, wines, and distilled alcoholic products. Apart from their social or recreational consumption, alcoholic beverages are also consumed as part of worship practices. In addition alcohol consumption has deep-rooted ritualistic importance among societies in Asia, Africa, and Latin America. Wine, in particular, has a long historical and socio-cultural significance in food habits of European and Mediterranean populations (Tamang, 2010a).

In contrast, wine has not been part of the tradition or culture in Asia, where fruits including grapes are generally consumed directly without fermentation. Instead, alcoholic beverages are usually made from cereals and potatoes that contain few fermentable carbohydrates (Aidoo & Nout, 2010; Tamang, 2010b; Tamang et al., 2016a; Sha et al., 2017, 2018). The latter require dried amylolytic starters. Thus, an enzyme-mediated saccharification step is necessary, commonly by fungal solid-state fermentation. In contrast to Europe and the United States, malting process for alcohol production is uncommon in Asia. Instead, traditionally prepared dry amylolytic starters are used to convert starches to sugars (Aidoo & Nout, 2010; Sha, Suryavanshi, & Tamang, 2019; Tamang, 2010a; Tamang et al., 2016a). This is one of the main distinctions between East and West. Historically, wine, whisky, and brandy were not traditional beverages of the East. However, due to colonial influences by Europeans in many Asian countries, such alcoholic drinks have become popular in East. Japan, in particular, has become a major producer of high-quality single-malt whisky (Hutkins, 2019)

4.10 | Other fermented products

One of the most popularly used flavoring agents in the world is vinegar. It is also very effective as a preservative, a property that must have also contributed to its long-history of use. Vinegar is prepared by a two-step process, starting with a sugar-to-ethanol, yeast-mediated fermentation to form a mash, followed by bacteria-mediated oxidation of the ethanol to form acetic acid (Solieri & Giudici, 2008). The original substrate from which the ethanol is produced can be any sugar-containing material, provided it is fermentable by yeast. These substrates can be either natural sugars, as would occur in grapes or other fruits, or derived via enzymatic hydrolysis of starchy materials, such as barley or rice. Vinegars are often distinguished based on the substrate, leading to many regional differences. Thus, grape wine and malt-style vinegars are popular in the West, and rice vinegars are more common in the East. Ultimately, the ethanol mashes are inoculated with acetic acid-producing microbes belonging to one of several genera, including *Acetobacter, Gluconoacetobacter,* or *Gluconobacter*. As for other fermentations, technologies and scale can vary significantly depending on region.

Although normal black tea is consumed on every continent, however, preferences vary considerably, from region to region. For example, traditionally fermented tea such as "miang" is frequently consumed in Thailand (Tanasupawat, Pakdeeto, Thawai, Yukphan, & Okada, 2007), whereas "puer tea," "fuzhuan brick," and kombucha are more commonly in China (Mo, Zhu, & Chen, 2008). *Aspergillus niger* is the predominant fungus in puer tea while other fungi *Blastobotrys adeninivorans, Asp. glaucus*, *Penicillium*, *Rhizopus*, and *Saccharomyces,* and some species of bacteria *Actinoplanes* and *Streptomyces* have also been reported (Abe et al., 2008). Long popular in the East, kombucha has become commercialized in the West. Several yeasts and bacteria have been isolated from the kombucha starter, known as SCOBY (symbiotic culture of bacteria and yeast). Fungi include *Brettanomyces bruxellensis, Candida stellata*, *Rhodotorula mucilaginosa, Saccharomyces* spp.*, Schizosaccharomyces pombe, Torulaspora delbrueckii, Zygosaccharomyces bailii, Z. bisporus, Z. kombuchaensis*, and *Z. microellipsoides* (Teoh, Heard, & Cox, 2004). Bacterial genera present in *kombucha* include *Gluconacetobacter*, *Lactobacillus*, and *Acetobacter* (Marsh, O'Sullivan, Hill, Paul Ross, & Cotter, 2014).

Nata is a bacterial cellulose product formed by *Komagataeibacter xylinus* (formerly, *Acetobacter xylinum*). It is one of the delicacies among Filipinos populations, and is most often made locally in small batches. Due to its somewhat sweet flavor nata is usually eaten as candy or dessert (Adams, 2014; Elegado et al., 2016). In the Philippines, two types of nata are commonly produced. "Nata de piña" is made from pineapple juice, whereas "nata de coco" is made from coconut water or skim milk (Adams, 2014). Nata is also used as food ingredient due to its high flavor, color, shapes, and textures (Shi, Zhang, Phillips, & Yang, 2014).

Pidan (or century egg) is a fermented egg of ducks mainly consumed in China (Ganasen and Bejakul, 2010).

The eggs are initially treated with alkaline salts that impart an ammoniacal flavor. Several species of *Bacillus* and *Staphylococcus* have been reported in *pidan* (Wang & Fung, 1996).

In the manufacture of chocolate, the cocoa bean fermentation is generally considered as a process aid, although it remains an essential step. Many different groups and general are involved, with *Lactobacillus* and other lactic acid bacteria as well as *Acetobacter pasteurianus* and other acetic acid-producing bacteria reported as the predominating bacterial species (Papalezandratou et al., 2011). Yeasts present in cocoa fermentation are mainly for pulp degradation and for flavor development (Schillinger, Ban-Koffi, & Franz, 2010).

Coffee is one of the most commonly consumed, non-alcoholic beverages in the world (Haile & Kang 2019). The oldest cultivated variety of coffee is *Coffea arabica* or "Arabica" coffee, with 75% to 80% of the world's production (Assiedu, 1991). The coffee fermentations characterized as a succession, with the initial stages dominated by *Enterobacter cloacae,* followed by *Klebsiella oxytoca, Hafnia alvei, Lb. plantarum*, and *Lb. brevis* (Huch & Franz, 2015). Several species of polygalacturonases-producing yeasts have been identified, including *Pichia anomala* and *P. kluyveri* (Masoud & Jespersen, 2006). They, as well as other yeasts and fungi, are important for degradation of pectin and other pulp components.

4.11 | Differences in the microbiomes in fermented foods and beverages between West and East

Microorganisms are ubiquitous in every eco-system including foods. However, their abundance in fermented foods and beverages varies depending on geography, climatic factors, surrounding environment, types of raw materials, and preparation methods. Studies on microbial succession during spontaneous fermentation (Giraffa, 2004; Li et al., 2014; Walsh et al., 2016; Wang, Du, Zhang, & Xu, 2018) reveal that many taxa of microorganisms, including potential pathogens and spoilage microbes, may be present in the surrounding environment during fermentation processes regardless of sources of raw material. If the atmosphere is anaerobic during spontaneous fermentations, LAB usually dominate the early stages of fermentation, suppressing pathogenic and spoilage microorganisms by secreting organic acids and lowering the pH (Mao & Yan 2019; Tamang & Tamang, 2010). Ultimately, dominance or abundance of particular genus/species at end product determines the characteristic of fermented foods and beverages. Interestingly, shotgun sequencing of cocoa beans has shown that even microbes present at low abundance (<1%) may still contribute to fermentation (Agyirifo et al., 2019).

Many of these lactic fermentations are often followed by fermentative and nonfermentative yeasts and other fungi. During ethanol fermentations, yeasts produce enzymes, aroma components, and other alcohols (Holt, Miks, de Carvalho, Foulquié-Moreno, & Thevelein, 2019). Most of the mycelial molds are obligate aerobes and grow aerobically, which may restrict their occurrence to few fermented foods mostly in the East. Molds produce extracellular proteolytic and lipolytic enzymes that may contribute in flavor and texture development of the product (Tamang & Fleet, 2009). Some filamentous fungi mostly *Aspergillus, Rhizopus, Mucor, Amylomyces*, and so on are dominant mycobiota in fermented foods of Asia (koji-*starter*, *shoyu, soya sauce, miso, doenjong, tempe*, etc.) and amylase- and alcohol-producing species of yeasts in amylolytic starters and alcoholic beverages of Asia, followed by different species of lactic acid bacteria mostly confined to fermented vegetables, milk, and cereal products. For example, *Aspergillus oryzae* is commonly used as a principal inoculum, and is commercially available as "koji," in production of many Asian (Japan, Korea, China, and Southeast Asia) fermented foods such as "soy sauce," "miso," "doenzong," and "sake," alcoholic beverage/drink sake, and so on since the 13th to 15th century CE (Machida, Yamada, & Gomi, 2008).

Another important fungus widely used in Asia is *Rhizopus.* Specifically, *Rhizopus microsporus* var. *oligosporous* is used as a starter culture for many fermented foods and beverages, but is mostly associated with "tempe," a fermented soybean food of Indonesia (Nout & Kiers, 2005; Tahir, Anwar, Mubeen, & Raza, 2018). Among yeasts, *Saccharomycopsis fubuligera* is very unique to Asian dry starters for alcohol production and other fermented foods (Lee, Jung, Seo, & Kim, 2018; Sha et al., 2018).

Finally, another group of fermented foods prepared and consumed mainly in Asian cultures are the soybean-based foods that rely on *Bacillus.* As noted previously, these fermented sticky, non-salty soybean foods are specific to only a few Asian countries as mentioned above. Regardless of region, however, *Bacillus subtilis* is the dominant bacterium in all of these Asian sticky fermented soybean foods, such as kinema, natto, chungkokjang, thua nao, and so on (Meerak et al., 2007; Kamada et al., 2015; Tamang, 2015). Interestingly, *Bacillus* is also involved in the fermentation of locust beans that are consumed in Africa (Oguntoyinbo, Sanni, Franz, & Holzapfel, 2007).

Collectively, as a general observation, filamentous fungi, mainly *Aspergillus* and *Rhizopus,* and *Bacillus* spp. dominate fermentations associated with Asian cuisines and cultures, these microbes are seldom found in Europe and North America (with the exception of mold-ripened cheeses and meats). Instead, LAB or a combination of bacteria (LAB and non-LAB) and yeast are more common. Similarly, soybeans and rice are the major substrate for Asian-fermented foods, but these are a relatively minor part of fermented food cultures in the West.

4.12 | A modern understanding of fermented foods and beverages

Research on fermented foods has advanced considerably in the modern "-omics" era as a consequence of sophisticated molecular and analytical techniques as well as the greater appreciation of the impact of microbial composition on product quality. Molecular tools are now routinely used to assess the ecological and functional dynamics for nearly every fermented food and beverage (Cocolin, Dolci, & Rantsiou, 2011; Ercolini et al., 2013; Haruta et al., 2006; Nam, Chang, Kim, Roh, & Bae, 2009; 2012; Wolfe & Dutton, 2015). Thus, omics approaches are now widely used to understand how these microbes affect physical–chemical–sensory properties of fermented foods, such as the metabolome and volatilome, and other functional and quality attributes. Importantly, these approaches are also being used to assess how consumption of fermented foods affects the human gut microbiome and human health.

Amplicon-based high-throughput sequencing and real time quantitative PCR, in particular, are commonly applied for profiling microbial community in naturally fermented foods with high accuracy (Alegría et al., 2011; Cocolin, Alessandria, Dolci, Gorra, & Rantsiou, 2013; Mayo et al., 2014; Puerari, Magalhães-Guedes, & Schwan, 2015; Tamang et al., 2016b; Shangpliang et al., 2018). These techniques also can be used to target different strains within a species (Ercolini et al., 2013), and also within a particular genus (Yan, Qian, Ji, Chen, & Han, 2013). In addition, several naturally fermented foods of Asia have been studied with metataxonomic or metagenetic approaches, revealing many rare, and unique species within the microbiome and mycobiome that had not been detected earlier (Jung et al., 2011; Kamada et al., 2014; Ly et al., 2018; Nam, Lee, & Lim, 2012; Park et al., 2019; Sha et al., 2018, 2019; Shangpliang et al., 2018; Yi et al., 2019). These omics approaches have led to validation of the so-called "ethnomicrobiology" of traditional food fermentations and have provided a basis for predictive functionality (Sha et al., 2019).

4.13 | Kefir as an example of a well interrogated fermented food

A representative example of how omics approaches have been applied to understand microbial ecology and product composition is for kefir. Kefir is a traditional fermented dairy food that originated in Europe and Asia and that has spread globally. Although kefir production is now industrialized, especially in the West, kefir is still widely produced on a local or artisanal basis using kefir grains as the culture inoculum. Omics based investigations of the composition of milk kefir and kefir grains were initially based on 16S rRNA- or ITS analyses of the microbiome and used only one or a small number of samples (Dobson, O'Sullivan, Cotter, Ross, & Hill, 2011). More recently, a larger number of products sampled multiple times during fermentation and sourced from various locations around the globe (Marsh, O'Sullivan, Hill, Ross, & Cotter, 2013) have been analyzed.

While amplicon-based investigations have proven valuable, they have been limited by virtue of permitting accurate identification of microbes only at the genus level. However, with the expanded use of shotgun metagenomic approaches, it has been possible to extensively interrogate these fermented milk microbiomes to identify the species, and even strains, present as well as the metabolic pathways that they encode (Walsh et al., 2016; Walsh et al., 2018). Importantly, such approaches may also provide quality control information relative the sourcing or origins of culture microbes (Seol et al., 2019). For example, one amplicon-based analysis of kefir from multiple western sources (i.e., Ireland,United Kingdom, Belgium, Spain, Germany, Italy, and the United States) revealed the absence of any clear clustering of the associated microbiomes on the basis of geography (Marsh et al., 2013). It was also apparent that the populations present in the fermented milk (kefir) were more homogeneous than the corresponding grains (kefir grains) from which they were produced. Indeed, *Lactococcus*, *Acetobacter*, *Lactobacillus*, *Leuconostoc*, and *Kazachstania* were the dominant genera within the kefirs, despite *Lactobacillus*, *Acetobacter*, and *Kazachstania* being dominant in the grains.

However, shotgun metagenomic sequencing of subset of the grains used in the previous study has revealed species-level differences. Thus, the dominant species were *Lactobacillus kefiranofaciens*, *Leuc. mesenteroides*, *Acetobacter pasteurianus*, *Lactobacillus helveticus*, *Leuconostoc citreum*, *Leuconostoc gelidum*, *Leuconostoc kimchi*, and *Saccharomyces cerevisiae* (Walsh et al., 2016; Walsh et al., 2018). Similar taxa were identified in kefir grains sourced in Brazil, Belgium, and across a variety of locations from Italy (Garofalo et al., 2015; Korsak et al., 2015; Leite et al., 2012).

In contrast, a relatively smaller number of grains from more Eastern countries have been investigated. From those that have been studied, a consistent pattern has emerged. More specifically, analysis of two Turkish grains highlighted the dominance of *L. kefiranofaciens*, *Lactobacillus buchneri*, and *L. helveticus* (Wegley, Edwards, Rodriguez-Brito, Liu, & Rohwer, 2007), while *L. kefiranofaciens* and *S. cerevisiae* were the dominant species in a study of Tibetan kefir grains (Wang et al., 2018). Thus, kefir grains collected from quite disparate locations have very similar microbial compositions.

In addition to revealing the microbial composition of kefir grains and milk, metagenomic information can be combined with metabolome data to identify correlations between specific taxa and volatile compounds. These findings provide opportunities to facilitate changes of the volatile profile by altering the microbial composition of the beverage (Walsh et al., 2016). Notably "omics"-based approaches have also contributed to insights into the health promoting attributes of kefir, as a representative health-associated fermented food (Kivanc & Yapici, 2018; Hsu et al., 2018; Jeong et al., 2017; Kim et al., 2019a; Kim et al., 2017; Kim, Jeong, Kim, & Seo, 2019b; Kok & Hutkins 2018).

4.14 | Omic approaches applied to other fermented foods

In the past decade, the microbiomes and metabolomes of a wide range of other fermented foods have been assessed. These include cheese (Bertuzzi et al., 2018; Bodinaku et al., 2019; Wolfe, Button, Santarelli, & Dutton, 2014), coffee (de Oliveira Junqueira et al., 2019), cocoa (Serra et al., 2019), wine (Bokulich et al., 2016; Lleixà, Kioroglou, Mas, & del Carmen Portillo, 2018), beer (Spitaels et al., 2015), bread (Weckx, Van Kerrebroeck, & De Vuyst, 2019), sausage (Ferrocino et al., 2018), and vinegar (Zhu et al., 2018). Interestingly, despite the disparate manufacturing locations, the microbiomes of these fermented foods and beverages are remarkably similar, even to the species level and even for products that are influenced by microbial succession.

Recently, the application of shotgun metataxonomics and metagenomics approaches have been applied to several Asian-fermented foods. Whole genome sequencing and functional analyses of kimchi-derived *Lactobacillus plantarum* strains showed that several strains could have probiotics properties, including the potential for improving immune health and inhibiting pathogens (Beck et al., 2019). Whole genome sequencing of natto-derived *Bacillus subtilis* strains has also been completed, including strain VK161 that overproduces vitamin K2 (Parks et al., 2019). Similarly, the genome of *Bacillus subtilis* BEST195 was also sequenced, revealing the presence of natto-specific functions (Kamada et al., 2014; Nishito, Osana, Hachiya, Popendorf, & Toyoda, 2010). Application of shotgun metagenomics based on nanopore technology in kinema, a miso-like sticky fermented soybean food of the eastern Himalayan regions of India, Nepal, and Bhutan showed the dominance of *Bacillus,* with many metabolic genes encoding for amino acid metabolism (Tamang et al., unpublished data). Final, metataxonomics and metagenomics approaches have been applied to profile microbial community metabolic functions in Chinese soy sauce (Sulaiman, Gan, Yin, & Chan, 2014) and Asian fermented vegetables (Peng et al., 2018).

4.15 | Fermented foods as delivery vehicles for probiotics to underserved communities

Most of the commercially available fermented foods currently in the marketplace are based on traditional foods that were originally obtained as a result of natural, wild or "spontaneous" fermentations. Spontaneous fermentations depend on microorganisms that are naturally present in the raw food, equipment, or from the environment (Leroy & De Vuyst 2004; Nout & Sarkar, 1999; Parker et al., 2018). Alternatively, a food ingredient that is rich in microbes (e.g., fruits, malted grains) can be added to the food matrix to initiate fermentation (Booysen, Dicks, Meijering, & Ackermann, 2002; Muyanja, Narvhus, Treimo, & Langsrud, 2003). Finally, the practice known as back-slopping—where a portion from a previously fermented food (such as fermented milk, sausage, or bread dough) is used to inoculate a new batch, has long been used to make fermented foods (Chelule, Mokoena, & Gqaleni, 2010; Franz et al., 2014; Leroy & De Vuyst, 2004; Nout & Sarkar, 1999).

Culture technology was introduced early in the 20th century, and within 50 years, this practice had been widely adopted by large-scale manufacturers. For many products, the use of well-defined cultures under controlled conditions is considered essential. Controlled fermentations using starter cultures allow for fast and consistent fermentation, high throughput on a large scale, reduction of spoilage, and increased food safety. The demand for such controlled products is also increasing among the growing urban population in middle- and low-income countries in Asia and sub-Saharan Africa. However, in most of these countries, there is a clear distinction between the urban population that consumes standardized, packed foods, and the rural population that produces natural fermented foods at home.

Perhaps the best example is for yoghurt, which was once produced by natural fermentation of milk, but which is now almost everywhere made using a starter culture containing *L. delbrueckii* subsp. *bulgaricus* and *S. thermophilus* (Chelule et al., 2010; Steinkraus, 1994). In addition to the benefits of controlled fermentations, the process also allows for the introduction of other specific strains, having known functional properties, into the yoghurt. These added strains may improve flavor, texture, or shelf-life.

Other strains are added due to their probiotic activity and their ability to enhance the nutritional quality of the yoghurt (Hill et al., 2014). Although many of the benefits provided by probiotics are strain-specific, others appear to be more broadly applied. In addition, different strains of the same species may exert different health benefits to the host. Among the health benefits that may be provided by probiotics are reductions in gastrointestinal-infections risk by enhancing intestinal barrier function (Bron et al., 2017).

One of the most critical health challenges in underserved communities is the prevalence of diarrhea. Diarrheal diseases are one of the leading causes of death among children under 5 years of age globally, with an estimated 1.5 million child deaths per year (WHO, 2009). In particular, rotavirus infections remain the most common cause of severe diarrhea among children worldwide. Each year rotavirus causes an estimate 111 million episodes of diarrhea requiring only home care, 2 million hospitalizations, and 400,000 deaths in children under 5 years; 82% of which occurs in children in the poorest countries (WHO, 2009).

Clinical evidence has shown that *Lactobacillus rhamnosus* GG can prevent and contribute to the recovery from rotavirus-associated diarrhea in children (Gorbach, 2000). Although the mechanism for this protective effect is not clear, it has been shown that *L. rhamnosus* GG is able to bind to the mucosal surface of the intestine (Kankainen et al., 2009), possibly protecting against intestinal pathogens and associated infections through immunomodulation (Segers & Lebeer 2014).

In response to these commonly faced health challenges in underserved communities, a tailor-made probiotic starter culture was developed for the production of yoghurt and other fermented foods (Kort & Sybesma 2012; Westerik, Wacoo, Sybesma, & Kort, 2016). This was consistent with the guidelines published of the FAO/WHO, stating that "Efforts should be made to make probiotic products more widely available, especially for relief work and populations at high risk of morbidity and mortality" (FAO and WHO, 2006). A variant of *L. rhamnosus* GG, *L. rhamnosus* (Kort & Sybesma, 2012; Sybesma, Molenaar, IJcken, Venema, & Kort, 2013) was used to make yoghurt. An adjuvant strain, *S. thermophilus* C106 enabled the *L. rhamnosus* strain to propagate in milk due to its endogenous proteolytic activity. The probiotic starter culture called "Yoba" is specifically developed for use by small scale producers in resource-poor setting, as it is packed in 1-gr packages for the production of 100 L of yoghurt, and is shelf stable for at least 6 months (Westerik et al., 2016).

Apart from creating access to healthy probiotic food in this part of the word, the concept also created employment and income for people active in the yoghurt production chain and provided farmers with market for their milk. The concept has currently been implemented in Uganda, Tanzania, Kenya, Rwanda, Zimbabwe, Nepal, and Indonesia. As the probiotics are grown in a food matrix of locally sourced food stuffs (most commonly milk), the probiotics are locally produced at very low cost. Hence, the simple innovation of incorporating a probiotic starter culture in a locally produced fermented food, will help consumers at the bottom of the pyramid to prevent diseases, even though they may consume the product without being aware of its health benefits. Indeed, so important are the potential health benefits of fermented foods, in the East as well as the West, that several researchers have suggested they be included as part of dietary guidelines (Bell, Ferrão, & Fernandes, 2017; 2018; Rezac, Kok, Heermann, & Hutkins, 2018),

4.16 | Improving hygienic standards and public health

Industrially produced fermented foods are usually manufactured in a hygienic environment. Indeed, many modern manufacturers observe Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Points (HACCP) that significantly reduces risks to public health. In contrast, traditional fermented foods (commonly produced by spontaneous fermentation or back-slopping) are produced at household levels and/or small factories often under hygienically inadequate and uncontrolled conditions. Thus, the risks of untoward events are inherently greater, warranting more stringent hygienic standards (Oguntoyinbo, 2014). Nonetheless, the act of fermentation as a method of food processing and preservation greatly increases the safety levels of both modern and traditional types of fermented foods, especially if carried out in conjunction with GMP or HACCP.

Fermentation improves food safety and public health via a number of important ways. First, fermentation-associated microbes will usually outcompete other microorganisms, leading to competitive exclusion of spoilage and pathogenic microbes. The organic acids produced by lactic acid bacteria and acetic acid bacteria are inhibitory to potential competitors. Alkalization via ammonia production can also be inhibitory. In alcohol fermentations, inhibitory levels of ethanol are produced. Microbes may also produce other inhibitory substances, including diacetyl, acetaldehydes, mycosin, and bacteriocins that restrict growth of other microbes. Finally, some fermented foods may contain added salt, sulfites, hops, nitrate, and nitrite, and other antimicrobial substances that present additional hurdles to growth and/or survival of spoilage and pathogenic microorganisms.

Even though fermented foods are generally considered as safe, there are still health risks associated with improperly fermented foods, especially those manufactured under poor hygienic conditions. To improve hygienic standards and protect public health, various measures should be implemented as suggested below and discussed elsewhere (Crowley, Mahony, & van Sinderen, 2013; Oguntoyinbo, 2014; Parkouda et al., 2009; Steinkraus, 2002). These include:

1. Education and information, especially for small-scale manufacturers;
2. Implementation of GMP and HACCP for all fermented foods manufacturers, with an emphasis on clean environment (water, air, etc.), sanitation, and workers' personal hygiene;
3. Use of starter cultures, protective cultures, and biopreservatives;
4. Selection and use of high-quality raw materials to reduce the load of undesirable microorganisms;
5. Proper pretreatment of raw materials using heat, sulfites, salt, and acids, prior to inoculation with cultures or initiation of spontaneous fermentation;
6. Fermentation under optimal conditions, including temperature, aerobic/anaerobic environment, and enclosed

tanks or vats, together with starter cultures to outcompete spoilage and pathogenic microorganisms;

7. Prevention of post-fermentation contamination during handling, processing, and packaging;
8. Further processing such as drying and heating after fermentation, before storage;
9. Cooking before consumption, where desirable;
10. Judicious practice of unproven/unconventional spontaneous fermentation involving molds to avoid development of mycotoxigenic fungi; and
11. Investment in modern equipment, facilities, and mechanization;

4.17 | Sustainability

Sustainability has emerged as one of the most significant global challenges in food and agriculture (FAO, 2017). Food sustainability has been defined as "food system(s) that support food security, makes optimal use of natural and human resources, and respects biodiversity and ecosystems for present and future generations, is culturally acceptable and accessible, environmentally sound, and economically fair and viable, and provides the consumer with nutritionally adequate, safe, healthy, and affordable food "(SUSFOOD 2013). Accordingly, sustainable food production and processing are important not only for family, artisan and other small-scale manufacturers in developing countries, but also for large, industrialized operations in the west.

Even before sustainability was recognized as an issue in agriculture, fermented foods were associated with many of the key elements. Raw materials used to make fermented dairy, vegetable, or meat products were traditionally obtained locally and provided consumers with safe, nutritious, and affordable foods. Fermentation is usually conducted under mild conditions, consuming little energy relative to other forms of food processing such as retorting (e.g., canning), spray-drying, and freeze-drying. During the production of some fermented foods/beverages such as yoghurt, fish sauces, and fermented cereals, few waste or by-products are generated.

In contrast, during the production of other fermented foods/beverages, large amounts of by-products are generated. Examples include spent grains and yeast lees from beer brewing, acid whey from cheese making and strained yoghurt, and grape sediments from wine making. These by-products would pose environmental problems if left untreated. In addition, manufacture of non-fermented foods and beverages, such as tofu (soybean curd) also generates a large volume of by-products such as soy pulp (okara) and soy whey. Fermentation may offer a way of food waste biovalorization by transforming these by-products into value-added ingredients and/or consumer products (Vong & Liu 2016; Chua & Liu, 2019).

As noted previously in this review, fermented foods have long been a part of social, cultural, and economic ecosystems. In developing countries, the manufacture of fermented foods creates demand for raw materials and provides jobs and food security, especially for disadvantaged populations (Adesulu & Awojobi, 2014). Efficiency has always been a key feature of fermented foods, from utilizing cheese whey for food, feed, or fertilizer, to the manufacture of fish sauces that use highly perishable fish that might otherwise spoil before they can be consumed as food (Kose & Hall, 2011).

Thus, fermentation of foods and beverages addresses many of the sustainability issues common to both developing and industrialized countries. Reducing waste, minimizing agricultural inputs, enhancing productivity, and increasing efficiency are all consistent with sustainability goals (Capone, El Bilali, Debs, Cardone, & Driouech, 2014). Furthermore, developing sustainable food supply chains for fermented foods, utilization of by-products, and conserving energy are just as critical for small as well as large food manufacturers (Waché et al., 2018). Likewise, safety is also a global sustainability issue, although strategies may vary. For example, the use of protective cultures or the addition of herbs that both provide biopreservation may be effective for non-pasteurized products to ensure food safety and shelf-life (Mahgoub, 2018).

5 | CONCLUSIONS

Throughout the world, nearly every community has a unique food culture that represents their ethnic, social, and cultural history. In particular, humans on every continent and for thousands of years have included fermented foods and beverages as a major part of their diets. The nutritional and cultural importance of these ancient foods continues in the present era. Indeed, fermented food and beverages are intimately associated with the regions or countries where these products are made. Examples include pulque of Mexico, sake of Japan, kimchi of Korea, and Roquefort cheese from France. For some of these foods, especially those produced in the developing world, the general manufacturing methods and scale of manufacture have changed relatively little.

In contrast, for most other fermented foods and beverages, the technologies and scale are dramatically different. Indeed, prior to the past 150 years, there was limited scientific understanding of even the fundamental features of fermentation or the role of microorganisms. Now, even for small scale fermentations conducted by traditional methods, microbial communities have been defined and characterized (Bourdichon et al., 2012). Ultimately, one of the main challenges facing scientists will be how to manage large-scale production of fermented foods without losing the unique flavors, textures, and other traits associated with the traditional products from which they are derived.

ACKNOWLEDGMENTS

This paper was based in part on an expert panel discussion session held at the International Scientific Association for Probiotics and Prebiotics Annual Meeting in Singapore in June, 2018. We thank Mary Ellen Sanders for helpful suggestions.

AUTHOR CONTRIBUTIONS

Each author contributed and edited sections to this manuscript. Hutkins and Tamang organized and edited the final manuscript.

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REFERENCES

Abe, M., Takaoka, N., Idemoto, Y., Takagi, C., Imai, T., & Nakasaki, K. (2008). Characteristic fungi observed in the fermentation process for Puer tea. *International Journal of Food Microbiology*, *124*, 199–203. https://doi.org/10.1016/j.ijfoodmicro.2008.03.008

Achaya, K. T. (2003). *The story of our food*. Delhi, India: Oxford University Press.

Adams, M. R. (1998). Fermented fish. In R. A. Lawley & P. Gibbs (Eds.), *Microbiology handbook fish and seafood* (Vol. 3, pp. 157–177). Surrey, UK: Leatherhead.

Adams, M. R. (2010). Fermented meat products. In J. P. Tamang & K. Kailasapathy (Eds.), *Fermented foods and beverages of the world* (pp. 309–322). New York, NY: CRC Press, Taylor & Francis Group.

Adams, M. R. (2014). Vinegar. In C. Batt & M. A. Tortorello (Eds.), *A: Encyclopaedia of food microbiology* (2nd edition, pp. 717–721)., Oxford, UK: Elsevier Ltd.

Adesulu, A. T., & Awojobi, K. O. (2014). Enhancing sustainable development through indigenous fermented food products in Nigeria. *African Journal of Microbiology Research*, *8*, 1338–1343. https://doi.org/10.5897/AJMR2013.5439

Agyirifo, D. S., Wamalwa, M., Otwe, E. P., Galyuon, I., Runo, S., Takrama, J., & Ngeranwa, J. (2019). Metagenomics analysis of cocoa bean fermentation microbiome identifying species diversity and putative functional capabilities. *Heliyon*, *5*(7), e02170. https://doi.org/10.1016/j.heliyon.2019.e02170.

Ahmed, Z., Wang, Y., Ahmad, A., Khan, S. T., Nisa, M., Ahmad, H., & Asma A. (2013). Kefir and health: A contemporary perspective. *Critical Reviews in Food Science and Nutrition*, *53*, 422–434. https://doi.org/10.1080/10408398.2010.540360

Aidoo, K. E., & Nout, M. R. (2010). Functional yeasts and molds in fermented foods and beverages. In J. P. Tamang & K. Kailasapathy (Eds.), *Fermented foods and beverages of the world* (pp. 127–148). New York, NY: CRC Press.

Alegría, Á., González, R., Díaz, M., & Mayo, B. (2011). Assessment of microbial populations dynamics in a blue cheese by culturing and denaturing gradient gel electrophoresis. *Current Microbiollogy*, *62*, 888–893. https://doi.org/10.1007/s00284-010-9799-7.

Al-Jedah, J. H., Ali, M. Z., & Robinson, R. K. (1999). Chemical and microbiological properties of *mehiawah* – a popular fish sauce in the Gulf golf. *Journal of Food Science and Technology*, *36*, 561–564.

Amoa-Awua, W. K., Terlabie, N. N., & Sakyi-Dawson, E. (2006). Screening of 42 *Bacillus* isolates for ability to ferment soybeans into *dawadawa*. *International Journal of Food Microbiology*, *106*, 343–347. https://doi.org/10.1016/j.ijfoodmicro.2005.08.016

Aponte, M., Ventorino, V., Blaiotta, G., Volpe, G., Farina, V., Avellone, G., … Moschetti, G. (2010). Study of green Sicilian table olive fermentations through microbiological, chemical and sensory analyses. *Food Microbiology*, *27*, 162–170. https://doi.org/10.1016/j.fm.2009.09.010

Arqués, J. L., Rodríguez, E., Langa, S., Landete, J. M., & Medina, M. (2015). Antimicrobial activity of lactic acid bacteria in dairy products and gut: Effect on pathogens. *Biomedical Research International*, 584183. https://doi.org/10.1155/2015/584183

Arroyo-López, F. N., Romero-Gil, V., Bautista-Gallego, J., Rodríguez-Gómez, F., Jiménez-Díaz, R., García-García, P., … Garrido-Fernández, A. (2012). Yeasts in table olive processing: Desirable or spoilage microorganisms? *International Journal of Food Microbiology*, *160*, 42–49. https://doi.org/10.1016/j.ijfoodmicro.2012.08.003

Assiedu, J. J. (1991). *Processing tropical crops: A technological approach*. London, UK: Macmillan.

Azokpota, P., Hounhouigan, D. J., & Nago, M. C. (2006). Microbiological and chemical changes during the fermentation of African locust bean (*Parkia biglobosa*) to produce afitin, iru, and sonru, three traditional condiments produced in Benin. *International Journal of Food Microbiology*, *107*, 304–309. https://doi.org/10.1016/j.ijfoodmicro.2005.10.026

Badham, C. D. (1854). *Prose halieutics or ancient and modern fish tattle*. London, UK: Parker and Sons.

Bartkiene, E., Bartkevics, V., Mozuriene, E., Lele, V., Zadeike, D., & Juodeikiene, G. (2019). The safety, technological, nutritional, and sensory challenges associated with lacto-fermentation of meat and meat products by using pure lactic acid bacteria strains and plant-lactic acid bacteria bioproducts. *Frontiers in Microbiology*, *10*, 1036. https://doi.org/10.3389/fmicb.2019.01036

Barrangou, R., Yoon, S.-S., Breidt, Jr. F., Fleming, H. P., & Klaenhammer, T. R. (2002). Characterization of six *Leuconostoc fallax* bacteriophages isolated from an industrial sauerkraut fermentation. *Applied and Environmental Microbiology*, *68*, 5452–5458. https://doi.org/10.1128/AEM.68.11.5452-5458.2002

Beganović, J., Kos, B., Pavunc, A. L., Uroić, K., Jokić, M., & Šušković, J. (2014). Traditionally produced sauerkraut as source of autochthonous functional starter cultures. *Microbiological Research*, *169*, 623–632. https://doi.org/10.1016/j.micres.2013.09.015

Beganović, J., Pavunc, A. L., Gjuračić, K., Špoljarec, M., Šušković, J., & Kos, B. (2011). Improved sauerkraut production with probiotic strain *Lactobacillus plantarum* L4 and *Leuconostoc mesenteroides* LMG 7954. *Journal of Food Science*, *76*, M124–M129. https://doi.org/10.1111/j.1750-3841.2010.02030.x

Beck, B. R., Park, G. S., Lee, Y. H., Im, S., Jeong, D. Y., & Kang, J. (2019). Whole genome analysis of *Lactobacillus plantarum* strains isolated from *kimchi* and determination of probiotic properties to treat mucosal infections by *Candida albicans* and *Gardnerella vaginalis*. *Frontiers in Microbiology*, *10*, 433. https://doi.org/10.3389/fmicb.2019.00433.

Bell, V., Ferrão, J., & Fernandes, T. (2017). Nutritional guidelines and fermented food frameworks. *Foods*, *6*, 1–17. https://doi.org/10.3390/foods6080065

Bell, V., Ferrão, J., & Fernandes, T. (2018). Fermented food guidelines for children. *Journal of Pediatrics and Pediatric Medicine*, *2*, 1–4.

Berbegal, C., Spano, G., Fragasso, M., Grieco, F., Russo, P., & Capozzi V. (2018). Starter cultures as biocontrol strategy to prevent *Brettanomyces bruxellensis* proliferation in wine. *Applied Microbiology and Biotechnology*, *102*(2), 569–576. https://doi.org/10.1007/s00253-017-8666-x.

Bertuzzi, A. S., Walsh, A. M., Sheehan, J. J., Cotter, P. D., Crispie, F., McSweeney, P. L., … Rea, M. C. (2018). Omics-based insights into flavor development and microbial succession within surface-ripened cheese. *MSystems*, *3*, e00211–17.

Bintsis, T. (2018). Lactic acid bacteria: their applications in foods. *Journal of Bacteriology & Mycology*, *6*(2), 89–94. https://doi.org/10.15406/jbmoa.2018.06.00182.

Bodinaku, I., Shaffer, J., Connors, A., Steenwyk, J., Kastman, E., Rokas, A., … Wolfe, B. (2019). Rapid phenotypic and metabolomic domestication of wild *Penicillium* molds on cheese. *MBio*, *10*, e02445–19. https://doi.org/10.1128/mBio.02445-19

Bokulich, N. A., Collins, T. S., Masarweh, C., Allen, G., Heymann, H., Ebeler, S. E., & Mills, D. A. (2016). Associations among wine grape microbiome, metabolome, and fermentation behavior suggest microbial contribution to regional wine characteristics. *MBio*, *7*, e00631–16. https://doi.org/10.1128/mBio.00631-16

Booysen, C., Dicks, L. M. T., Meijering, I., & Ackermann, A. (2002). Isolation, identification and changes in the composition of lactic acid bacteria during the malting of two different barley cultivars. *International Journal of Food Microbiology*, *76*, 63–73. https://doi.org/10.1016/S0168-1605(02)00007-7

Boskou, D. (2008). Phenolic compounds in olives and olive oil. In D. Boskou (Ed.), *Olive oil minor constituents and health* (pp. 11–44). Boca Raton, FL: CRC Press.

Bourdichon, F., Casaregola, S., Farrokh, C., Frisvad, J. C., Gerds, M. L., Hammes, W. P., … Hansen, E. B. (2012). Food fermentations: Microorganisms with technological beneficial use. *International Journal of Food Microbiology*, *154*(3), 87–97. https://doi.org/10.1016/j.ijfoodmicro.2011.12.030

Bourrie, B. C., Cotter, P. D., & Willing, B. P. (2018). Traditional kefir reduces weight gain and improves plasma and liver lipid profiles more successfully than a commercial equivalent in a mouse model of obesity. *Journal of Functional Foods*, *46*, 29–37. https://doi.org/10.1016/j.jff.2018.04.039

Bron, P. A., Kleerebezem, M., Brummer, R. J., Cani, P. D., Mercenier, A., MacDonald, T. T., … Wells, J. M. (2017). Can probiotics modulate human disease by impacting intestinal barrier function? *British Journal of Nutrition*, *117*, 93–107. https://doi.org/10.1017/S0007114516004037

Campbell-Platt, G. (1987). *Fermented foods of the world: A dictionary and guide*. London, UK: Butterworths.

Capone, R., El Bilali, H., Debs, P., Cardone, G., & Driouech, N. (2014). Food system sustainability and food security: Connecting the dots. *Journal of Food Security*, *2*, 13–22. https://doi.org/10.12691/jfs-2-1-2.

Carr, F. J., Chill, D., & Maida, N. (2002). The lactic acid bacteria: A literature survey. *Critical Reviews in Microbiology*, *28*, 281–370. https://doi.org/10.1080/1040-840291046759

Chang, J. H. (1975). Studies on the origin of Korean vegetable pickles. *Thesis Collection of Sung-Sim Women College*, *6*, 149–174.

Chelule, P. K., Mokoena, M. P., & Gqaleni, N. (2010). Advantages of traditional lactic acid bacteria fermentation of food in Africa. *Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology*, *2*, 1160–1167.

Choi, D. K. (2009). Reexamination of the origin of soybean and the distribution of soybean sauce, soybean malt, and sundubu: From the documentary and excavated data from the ancient China. *Yŏksa Minsokhak*, *30*, 363–427.

Chua, J. Y., & Liu, S.-Q. (2019). Soy whey: More than just wastewater from tofu and soy protein isolate industry. *Trends in Food Science and Technology*, *91*, 24–32. https://doi.org/10.1016/j.tifs.2019.06.016

Cocolin, L., Alessandria, V., Dolci, P., Gorra, R., & Rantsiou, R. (2013). Culture-independent methods to assess the diversity and dynamics of microbiota during food fermentation. *International Journal of Food Microbiology*, *167*, 29–43. https://doi.org/10.1016/j.ijfoodmicro.2013.05.008

Cocolin, L., Dolci, P., & Rantsiou, K. (2011). Biodiversity and dynamics of meat fermentations: The contribution of molecular methods for a better comprehension of a complex ecosystem. *Meat Science*, *89*, 296–302. https://doi.org/10.1016/j.meatsci.2011.04.011

Crowley, S., Mahony, J., & van Sinderen, D. (2013). Current perspectives on antifungal lactic acid bacteria as natural biopreservatives. *Trends in Food Science & Technology*, *33*, 93–109. https://doi.org/10.1016/j.tifs.2013.07.004

Curtis, R. I. (2001). *Ancient food technology*. Leiden, the Netherlands: Brill.

Damerow, P. (2012). Sumerian beer: The origins of brewing technology in ancient Mesopotamia. *Cuneiform Digital Library Journal*, *2*, 1–20.

de Oliveira Junqueira, A. C., de Melo Pereira, G. V., Medina, J. D. C., Alvear, M. C., Rosero, R., de Carvalho Neto, D. P., … Soccol, C. R. (2019). First description of bacterial and fungal communities in Colombian coffee beans fermentation analysed using Illumina-based amplicon sequencing. *Scientific Reports*, *9*, 8794. https://doi.org/10.1038/s41598-019-45002

de Ramesh, C. C., White, C. H., Kilara, A., & Hui, Y. H. (2006). *Manufacturing yogurt and fermented milks*. Oxford, UK: Blackwell Publishing.

Devi, K. R., Deka, M., & Jeyaram, K. (2015). Bacterial dynamics during yearlong spontaneous fermentation for production of *ngari*, a dry fermented fish product of Northeast India. *International Journal of Food Microbiology*, *199*, 62–71. https://doi.org/10.1016/j.ijfoodmicro.2015.01.004

Dewan, S., & Tamang, J. P. (2006). Microbial and analytical characterization of *Chhu*, a traditional fermented milk product of the Sikkim Himalayas. *Journal of Scientific and Industrial Research*, *65*, 747–752.

Dewan, S., & Tamang, J. P. (2007). Dominant lactic acid bacteria and their technological properties isolated from the Himalayan ethnic fermented milk products. *Antonie van Leeuwenhoek*, *92*, 343–352. https://doi.org/10.1007/s10482-007-9163-5

Dias, F. S., Santos, M. R. R.M., & Schwan, R. F. (2015). Enumeration, identification and safety proprieties of lactic acid bacteria isolated from pork sausage. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, *67*, 918–926. https://doi.org/10.1590/1678-4162-8119

Dobson, A., O'Sullivan, O., Cotter, P. D., Ross, P., & Hill, C. (2011). High-throughput sequence-based analysis of the bacterial composition of kefir and an associated kefir grain. *FEMS Microbiology Letters*, *320*, 56–62. https://doi.org/10.1111/j.1574-6968.2011.02290.x

El-Baradei, G., Delacroix-Buchet, A., & Ogier, J. C. (2008). Bacterial biodiversity of traditional Zabady fermented milk. *International Journal of Food Microbiology*, *121*, 295–301. https://doi.org/10.1016/j.ijfoodmicro.2007.11.014

Elegado, F. B., Colegio, S. M. T., Lim, V. M. T., Gervasio, A. T. R., Perez, M. T. A., Balolong, M. P., … Mendoza, B. C. (2016). Ethnic fermented foods of the Philippines with reference to lactic acid bacteria and yeasts. In J. P. Tamang (Ed.), *Ethnic fermented foods and alcoholic beverages of Asia* (pp. 323–340). New Delhi, India: Springer Nature.

Encinas, J. P., Lopez-Diaz, T.M., Garcia-Lopez, M.L., Otero, A., & Moreno, B. (2000). Yeast populations on Spanish fermented sausages. *Meat Science*, *54*, 203–208. https://doi.org/10.1016/S0309-1740(99)00080-7

Ercolini, D., Pontonio, E., De Filippis, F., Minervini, F., La Storia, A., Gobbetti, M., & Di Cagno, R. (2013). Microbial ecology dynamics during rye and wheat sourdough preparation. *Applied and Environmental Microbiology*, *79*, 7827–7836. https://doi.org/10.1128/AEM.02955-13

FAO & WHO, (2006). Probiotics in food: Health and nutritional properties and guidelines for evaluation. Rome: Author.

Ferrocino, I., Bellio, A., Giordano, M., Macori, G., Romano, A., Rantsiou, K., … Cocolin, L. (2018). Shotgun metagenomics and volatilome profile of the microbiota of fermented sausages. *Applied and Environmental Microbiology*, *84*, e02120–17. https://doi.org/10.1128/AEM.02120-17.

Food and Agriculture Organization of the United Nations (FAO). (2017). *The future of food and agriculture. Trends and challenges*. Rome: Author. Retrieved from http://www.fao.org/3/a-i6583e.pdf

Fox, P. F., Guinee, T. P., Cogan, T. M., & McSweeney, P. L. H. (2000). Fundamentals of cheese science. Gaithersburg, MD: AN Aspen Publication.

Franciosa, I., Alessandria, V., Dolci, P., Rantsiou, K., & Cocolin, L. (2018). Sausage fermentation and starter cultures in the era of molecular biology methods. *International Journal of Food Microbiology*, *279*, 26–32. https://doi.org/10.1016/j.ijfoodmicro.2018.04.038.

Franz, C. M. A.P., Huch, M., Mathara, J. M., Abriouel, H., Benomar, N., Reid, G., … Holzapfel, W. H. (2014). African fermented foods and probiotics. *International Journal of Food Microbiology*, *190*, 84–96. https://doi.org/10.1016/j.ijfoodmicro.2014.08.033

Ganasen, P., & Benjakul, S. (2010). Physical properties and microstructure of pidan yolk as affected by different divalent and monovalent cations. *LWT - Food Science and Technology*, *43*, 77–85. https://doi.org/10.1016/j.lwt.2009.06.007

Garofalo, C., Osimani, A., Milanović, V., Aquilanti, L., De Filippis, F., Stellato, G., … Clementi, F. (2015). Bacteria and yeast microbiota in milk kefir grains from different Italian regions. *Food Microbiology*, *49*, 123–133. https://doi.org/10.1016/j.fm.2015.01.017

Giraffa, G. (2004). Studying the dynamics of microbial populations during food fermentation. *FEMS Microbiology Reviews*, *28*(2), 251–260. https://doi.org/10.1016/j.femsre.2003.10.005

Gode, P. K. (1943). Some notes on the history of Indian dietetics with special reference to the history of jalebi. *New Indian Antique*, 169–181.

Goncalves de Lima, O. (1975). *Pulque, balche e pajuaru*. Recife, Brazil: Universidade Federal de Pernambuco.

Gorbach, S. L. (2000). Probiotics and gastrointestinal health. *American Journal of Gastroenterology*, *95*, S2–S4. https://doi.org/10.1016/S0002-9270(99)00806-0

Haile, M. & Kang, W.H. (2019). The role of microbes in coffee fermentation and their impact on coffee quality. *Journal of Food Quality*, 4836709. https://doi.org/10.1155/2019/4836709.

Hara, T., Zhang, J. R., & Ueda, S. (1983). Identification of plasmids linked with polyglutamate production in *Bacillus subtilis (natto)*. *Journal of General and Applied Microbiology*, *29*, 345–354.

Hara, T., Chetanachit, C., Fujio, Y., & Ueda, S. (1986). Distribution of plasmids in polyglutamate-producing *Bacillus* strains isolated from "natto"—like fermented soybeans, "thua nao," in Thailand. *Journal of General and Applied Microbiology*, *32*, 241–249.

Hara, T., Hiroyuki, S., Nobuhide, I., & Shinji, K. (1995). Plasmid analysis in polyglutamate-producing *Bacillus* strain isolated from non-salty fermented soybean food, "kinema", in Nepal. *Journal of General and Applied Microbiology*, *41*, 3–9.

Haruta, S., Ueno, S., Egawa, I., Hashiguchi, K., Fujii, A., Nagano, M., & Igarashi, Y. I. (2006). Succession of bacterial and fungal communities during a traditional pot fermentation of rice vinegar assessed by PCR-mediated denaturing gradient gel electrophoresis. *International Journal of Food Microbiology*, *109*, 79–87. https://doi.org/10.1016/j.ijfoodmicro.2006.01.015

Heperkan, D. (2013). Microbiota of table olive fermentations and criteria of selection for their use as starters. *Frontiers in Microbiology*, *4*, 143. https://doi.org/10.3389/fmicb.2013.00143

Hesseltine, C. W. (1983). Microbiology of oriental fermented foods. *Annual Review of Microbiology*, *37*, 575–601.

Hesseltine, C. W., & Wang, H. L. (1980). The importance of traditional fermented foods. *BioScience*, *30*, 402–404.

Hill, C., Guarner, F., Reid, G., Gibson, G. R., Merenstein, D. J., Pot, B., … Salminen, S. (2014). Expert consensus document: The International Scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic. *Nature Reviews in Gastroenterology and Hepatology*, *11*, 506. https://doi.org/10.1038/nrgastro.2014.66.

Holt, S., Miks, M. H., de Carvalho, B. T., Foulquié-Moreno, M. R., & Thevelein, J. M. (2019). The molecular biology of fruity and floral aromas in beer and other alcoholic beverages. *FEMS Microbiology Reviews*, *43*(3), 193–222. https://doi.org/10.1093/femsre/fuy041

Hsu, Y. J., Huang, W. C., Lin, J. S., Chen, Y. M., Ho, S. T., Huang, C. C., & Tung, Y. T. (2018). Kefir supplementation modifies gut microbiota composition, reduces physical fatigue, and improves exercise performance in mice. *Nutrients*, *10*, 862. https://doi.org/10.3390/nu10070862

Huang, H. T. (2000). Fermentations and Food Science. In J. Needham (Ed.). *Science and Civilisation in China*: Volume 6, Part 5, Cambridge University Press. *424*(144), 44.

Huch, M., & Franz, C. M. A.P. (2015). Coffee: Fermentation and microbiota. In W. Holzapfel (Ed.), *Advances in fermented foods and beverages: Improving quality, technologies and health benefits* (pp. 501–513). Woodhead Publishing Series in Food Science, Technology and Nutrition No. 265. Cambridge, MA: Elsevier.

Hutkins, R. (2019). *Microbiology and technology of fermented foods*. London, UK: Wiley Press.

Hwanhlem, N., Buradaleng, S., Wattanachant, S., Benjakul, S., Tani, A., & Maneerat, S. (2011). Isolation and screening of lactic acid bacteria from Thai traditional fermented fish (*Plasom*) and production of *Plasom* from selected strains. *Food Control*, *22*, 401–407. https://doi.org/10.1016/j.foodcont.2010.09.010

Hymowitz, T. (1970). On the domestication of the soybean. *Economic Botany*, *24*, 408–421.

Ishige, N. (1986). *Narezushi* in Asia - A study of fermented aquatic products (2). *Bulletin of the National Museum of Ethnology*, *11*(3), 603–668. (Japanese)

Ishige, N. (1993). Cultural aspects of fermented fish products in Asia. In C. H. Lee, Steinkraus K.H., & P. J. Alan Reilly (Eds.), *Fish fermentation technology* (pp. 13–32). Tokyo: United Nations University Press.

Ito, H., Tong, J., & Li, Y. (1996). Chinese dauchi, from itohiki natto to nonmashed miso. *Miso Science Technology*, *44*, 224–250.

Jang, D. J., Chung, K. R., Yang, H. J., Kim, K. S., & Kwon, D. Y. (2015). Discussion on the origin of kimchi, representative of Korean unique fermented vegetables. *Journal of Ethnic Foods*, *2*, 126–136. https://doi.org/10.1016/j.jef.2015.08.005

Jeong, D., Kim, D. H., Kang, I. B., Kim, H., Song, K. Y., Kim, H. S., & Seo, K. H. (2017). Modulation of gut microbiota and increase in fecal water content in mice induced by administration of *Lactobacillus kefiranofaciens* DN1. *Food & function*, *8*, 680–686. https://doi.org/10.1039/C6FO01559J

Jung, J. Y., Lee, S. H., Kim, J. M., Park, M. S., Bae, J. W., Hahn, Y., … Jeon, C. O. (2011). Metagenomic analysis of kimchi, a traditional Korean fermented food. *Applied and Environmental Microbiology*, *77*, 2264–2274. https://doi.org/10.1128/AEM.02157-10

Kamada, M., Hase, S., Sato, K., Toyoda, A., Fujiyama, A., & Sakakibara, Y. (2014). Whole genome complete resequencing of *Bacillus subtilis* natto by combining long reads with high-quality short reads. *PLOS ONE*, *9*(10), e109999. https://doi.org/10.1371/journal.pone.0109999

Kankainen, M., Paulin, L., Tynkkynen, S., von Ossowski, I., Reunanen, J., Partanen, P. … de Vos, W.M. (2009). Comparative genomic analysis of Lactobacillus rhamnosus GG reveals pili containing a human-mucus binding protein. *Proceedings of the National Academy of Sciences of the United States of America*. *106*(40), 17193–17198. https://doi.org/10.1073/pnas.0908876106.

Khanh, T. M., May, B. K., Smooker, P. M., Van, T. T. H., & Coloe, P. J. (2011). Distribution and genetic diversity of lactic acid bacteria from traditional fermented sausage. *Food Research International*, *44*, 338–344. https://doi.org/10.1016/j.foodres.2010.10.010

Kim, D. H., Jeong, D., Kang, I. B., Lim, H. W., Cho, Y., & Seo, K. H. (2019a). Modulation of the intestinal microbiota of dogs by kefir as a functional dairy product. *Journal of Dairy Science*, https://doi.org/10.3168/jds.2018-15639

Kim, D. H., Kim, H., Jeong, D., Kang, I. B., Chon, J. W., Kim, H. S., … Seo, K. H. (2017). Kefir alleviates obesity and hepatic steatosis in high-fat diet-fed mice by modulation of gut microbiota and mycobiota: Targeted and untargeted community analysis with correlation of biomarkers. *The Journal of Nutritional Biochemistry*, *44*, 35–43. https://doi.org/10.1016/j.jnutbio.2017.02.014

Kim, D. H., Jeong, D., Kim, H., & Seo, K. H. (2019b). Modern perspectives on the health benefits of kefir in next generation sequencing era: Improvement of the host gut microbiota. *Critical reviews in food science and nutrition*, *59*(11), 1782–1793.

Kiuchi, K. (2001). Miso and natto. *Food Culture*, *3*, 7–10

Kivanc, M., & Yapici, E. (2018). Survival of *Escherichia coli* O157: H7 and Staphylococcus aureus during the fermentation and storage of kefir. *Food Science and Technology, 39, Supplement*, *1*, https://doi.org/10.1590/fst.39517

Kobayashi, T., Kimura, B., & Fujii, T. (2000a). Differentiation of *Tetragenococcus* populations occurring in products and manufacturing processes of puffer fish ovaries fermented with rice-bran. *International Journal of Food Microbiology*, *56*, 211–218. https://doi.org/10.1016/S0168-1605(00)00214-2

Kobayashi, T., Kimura, B., & Fujii, T. (2000b). *Haloanaerobium fermentans* sp. nov., a strictly anaerobic, fermentative halophile isolated from fermented puffer fish ovaries. *International Journal of Systematic and Evolutionary Microbiology*, *50*, 1621–1627. https://doi.org/10.1099/00207713-50-4-1621

Kok, C. R., & Hutkins, R. (2018). Yogurt and other fermented foods as sources of health-promoting bacteria. *Nutrition Reviews*, *76*(Supplement_1), 4–15. https://doi.org/10.1093/nutrit/nuy056

Kong, S., & Park, J. H. (2019). Effect of bacteriophages on viability and growth of co-cultivated *Weissella* and *Leuconostoc* in *kimchi* fermentation. *Journal of Microbiology and Biotechnology*, *29*(4), 558–561.

Korsak, N., Taminiau, B., Leclercq, M., Nezer, C., Crevecoeur, S., Ferauche, C., … Daube, G. (2015). Evaluation of the microbiota of kefir samples using metagenetic analysis targeting the 16S and 26S ribosomal DNA fragments. *Journal of Dairy Science*, *98*(6). pp. , 3684–3689.

Kort, R., & Sybesma, W. (2012). Probiotics for every body. *Trends in Biotechnology*, *30*, 613–615. https://doi.org/10.1016/j.tibtech.2012.09.002

Kosikowski, F. V., & Mistry, V. V. (1997). Cheese and fermented milk foods. (3rd edition)., ed., F. V. Kosikowski Connecticut: LLC Westport.

Kose, S., & Hall, G. M. (2011). Sustainability of fermented fish-products. *Fish processing: Sustainability and new opportunities*, 138–166.

Krishna Jois, S. N. (1969). Supa sastra of mangarasa *(AD 1516)* (pp. 3–252). Mysore, India: University of Mysore.

Laranjo, M., Elias, M., & Fraqueza, M. J. (2017). The use of starter cultures in traditional meat products. *Journal of Food Quality*, *2017*, 9546026. https://doi.org/10.1155/2017/9546026.

Laufer, B. (1914). Some fundamental ideas of Chinese culture. *Journal of Race Development*, *5*, 160–174.

Law, B. A. (1999). *Technology of cheesemaking*. Boca Raton: CRC Press.

Lee, C. H., & Kim, M. L. (2016). History of Fermented Foods in Northeast Asia. In J. P. Tamang (Ed.), *Ethnic fermented foods and alcoholic beverages of Asia* (pp. 1–16). New Delhi: Springer Nature.

Lee, M. E., Jang, J. Y., Lee, J. H., Park, H. W., Choi, H. J., & Kim, T. W. (2015). Starter cultures for kimchi fermentation. *Journal of Microbiology and Biotechnology*, *25*(5), 559–568. https://doi.org/10.4014/jmb.1501.01019.

Lee, S. M., Jung, J. H., Seo, J. A., & Kim, Y. S. (2018). Bioformation of volatile and nonvolatile metabolites by *Saccharomycopsis fibuligera* KJJ81 cultivated under different conditions—carbon sources and cultivation times. *Molecules*, *23*, 2762. https://doi.org/10.3390/molecules23112762.

Legras, J. L., Merdinoglu, D., Cornuet, J. M., & Karst, F. (2007). Bread, beer and wine: *Saccharomyces cerevisiae* diversity reflects human history. *Molecular Ecology*, *16*, 2091–2102. https://doi.org/10.1111/j.1365-294X.2007.03266.x

Leite, A. M., Mayo, B., Rachid, C. T., Peixoto, R. S., Silva, J. T., Paschoalin, V. M. F., & Delgado, S. (2012). Assessment of the microbial diversity of Brazilian kefir grains by PCR-DGGE and pyrosequencing analysis. *Food Microbiology*, *31*, 215–221. https://doi.org/10.1016/j.fm.2012.03.011

Leroy, F., & De Vuyst, L. (2004). Lactic acid bacteria as functional starter cultures for the food fermentation industry. *Trends in Food Science and Technology*, *15*, 67–78. https://doi.org/10.1016/j.tifs.2003.09.004

Li, H., Wang, H., Li, H., Goodman, S., van der Lee, P., Xu, Z., … Yang, P. (2018). The worlds of wine: Old, new and ancient. *Wine Economics and Policy*, *7*, 178–182. https://doi.org/10.1016/j.wep.2018.10.002.

Li, K., Lin, K., Li, Z., Zhang, Q., Song, F., Che, Z., … Xiang, W. (2014). Spoilage and pathogenic bacteria associated with spoilage process of Sichuan pickle during the spontaneous fermentation. *Food Science and Technology Research*, *20*(4), 899–904. https://doi.org/10.3136/fstr.20.899.

Lick, S., Drescher, K., & Heller, K. J. (2001). Survival of *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* in the terminal ileum of fistulated Göttingen minipigs. *Applied and Environmental Microbiology*, *67*, 4137–4143. https://doi.org/10.1128/aem.67.9.4137-4143.2001.

Lleixà, J., Kioroglou, D., Mas, A., & del Carmen Portillo, M. (2018). Microbiome dynamics during spontaneous fermentations of sound grapes in comparison with sour rot and *Botrytis* infected grapes. *International Journal of Food Microbiology*, *281*, 36–46. https://doi.org/10.1016/j.ijfoodmicro.2018.05.016

Lücke, F. K. (1988). Fermented sausages. In B. J. B. Wood (Ed.), *Microbiology of fermented foods* (2nd Ed., Vol. 2, pp. 441–483). London: Blackie Academic and Professional.:

Lücke, F. K. (2003). Fermented meat products. In B. Carballero, L. C. Trugo, & P. M. Finglas (Eds.), *Encyclopedia of food sciences and nutrition* (2nd edition, pp. 2338–2343). London, UK: Academic Press.

Lücke, F. K. (2015). Quality improvement and fermentation control in meat products. In W. H. Holzapfel (Ed.), *Advances in fermented foods and beverages. Improving quality, technologies and health benefits* (pp. 357–376). Woodhead Publishing Series in Food Science, Technology and Nutrition No. 26. Cambridge, UK: Woodhead Publishing,

Ly, S., Mith, H., Tarayre, C., Taminiau, B., Daube, G., Fauconnier, M. L., & Delvigne, F. (2018). Impact of microbial composition of Cambodian traditional dried starters (Dombea) on flavor compounds of rice wine: Combining amplicon sequencing with HP-SPME-GCMS. *Frontiers in Microbiology*, *9*, 894. https://doi.org/10.3389/fmicb.2018.00894

Machida, M., Yamada, O., & Gomi, K. (2008). Genomics of *Aspergillus oryzae*: Learning from the history of Koji mold and exploration of its future. *DNA Research*, *15*(4), 173–183. https://doi.org/10.1093/dnares/dsn020

Mahgoub, S. A. (2018). Fermented Food in Egypt: A Sustainable Bio-preservation to Improve the Safety of Food. In A. M. Negm & M. Abu-hashim (Eds.), *Sustainability of agricultural environment in Egypt: Part I* (pp. 231–251). Cham, Switzerland: Springer.

Mao, B., & Yan, S. (2019). Lactic Acid Bacteria and Fermented Fruits and Vegetables. In W. Chen (Ed.) *Lactic acid bacteria*. Singapore: Springer.

Marco, M. L., Heeney, D., Binda, S., Cifelli, C. J., Cotter, P. D., Foligne, B., … Hutkins, R. (2017). Health benefits of fermented foods: Microbiota and beyond. *Current Opinion in Biotechnology*, *44*, 94–102. https://doi.org/10.1016/j.copbio.2016.11.010

Marsh, A. J., O'Sullivan, O., Hill, C., Ross, R. P., & Cotter, P. D. (2013). Sequencing-based analysis of the bacterial and fungal composition of kefir grains and milks from multiple sources. *PLoS One*, *8*, e69371. https://doi.org/10.1371/journal.pone.0069371

Marsh, A. J., O'Sullivan, O., Hill, C., Paul Ross, R. P., & Cotter, D. (2014). Sequence-based analysis of the bacterial and fungal compositions of multiple kombucha (tea fungus) samples. *Food Microbiology*, *38*, 171–178. https://doi.org/10.1016/j.fm.2013.09.003

Marty, E., Buchs, J., Eugster-Meier, E., Lacroix, C., & Meile, L. (2011). Identification of staphylococci and dominant lactic acid bacteria in spontaneously fermented Swiss meat products using PCR–RFLP. *Food Microbiology*, *29*, 157–166. https://doi.org/10.1016/j.fm.2011.09.011

Masoud, W., & Jespersen, L. (2006). Pectin degrading enzymes in yeasts involved in fermentation of *Coffea arabica* in East Africa. *International Journal of Food Microbiology*, *110*, 291–296. https://doi.org/10.1016/j.ijfoodmicro.2006.04.030

Mayo, B., Ammor, M. S., Delgado, S., & Alegría, A. (2010). Fermented milk products. In J. P. Tamang & K. Kailasapathy (Eds.), *Fermented foods and beverages of the world* (pp. 263–288). New York, NY: CRC Press.

Mayo, B., Rachid, C. T. C.C., Alegría, Á., Leite, M. O., Peixoto, R. S., & Delgado, S. (2014). Impact of next generation sequencing techniques in food microbiology. *Current Genomics*, *15*, 293–309. https://doi.org/10.2174/1389202915666140616233211

McGovern, P. E., Glusker, D. L., Exner., L. J., & Voigt, M. M. (1996). Neolithic resinated wine. *Nature*, *381*, 480–481. https://doi.org/10.1038/381480a0

McGovern, P., Jalabadze, M., Batiuk, S., Callahan, M. P., Smith, K. E., Hall, G. R., … Failla, O. (2017). Early Neolithic wine of Georgia in the South Caucasus. *Proceedings of the National Academy of Sciences of the United States of America*, *114*, E10309–E10318. https://doi.org/10.1073/pnas.1714728114

McGovern, P. E., Zhang, J., Tang, J., Zhang, Z., Hall, G. R., Moreau, R. A., … Cheng, G. (2004). Fermented beverages of pre- and proto-historic China. *Proceedings of the National Academy of Sciences of the United States of America*, *101*, 17593–17598. https://doi.org/10.1073/pnas.0407921102

Meerak, J., Iida, H., Watanabe, Y., Miyashita, M., Sato, H., Nakagawa, Y., & Tahara, Y. (2007). Phylogeny of γ-polyglutamic acid-producing *Bacillus* strains isolated from fermented soybean foods manufactured in Asian countries. *Journal of General and Applied Microbiology*, *53*, 315–323.

Meerak, J., Yukphan, P., Miyashita, M., Sato, H., Nakagawa, Y., & Tahara, Y. (2008). Phylogeny of γ-polyglutamic acid-producing *Bacillus* strains isolated from a fermented locust bean product manufactured in West Africa. *Journal of General and Applied Microbiology*, *54*, 159–166. https://doi.org/10.2323/jgam.54.159

Mo, H., Zhu, Y., & Chen, Z. (2008). Microbial fermented tea – a potential source of natural food preservatives. *Trends in Food Science and Technology*, *19*, 124–130. https://doi.org/10.1016/j.tifs.2007.10.001

Muyanja, C. M. B. K., Narvhus, J. A., Treimo, J., & Langsrud, T. (2003). Isolation, characterisation and identification of lactic acid bacteria from bushera: A Ugandan traditional fermented beverage. *International Journal of Food Microbiology*, *80*, 201–210. https://doi.org/10.1016/S0168-1605(02)00148-4

Muzaddadi, A. U., & Basu, S. (2012). *Shidal* - a traditional fermented fishery product of North East India. *Indian Journal of Traditional Knowledge*, *11*, 323–328.

Nakao, S. (1972). *Ryori no kigen (in Japanese)*. (pp. 121). Tokyo: NHK Press, Tokyo.

Nam, Y. D., Chang, H. W., Kim, K. H., Roh, S. W., & Bae, J. W. (2009). Metatranscriptome analysis of lactic acid bacteria during kimchi fermentation with genome-probing microarrays. *International Journal of Food Microbiology*, *130*, 140–146. https://doi.org/10.1016/j.ijfoodmicro.2009.01.007

Nam, Y. D., Lee, S. Y., & Lim, S. I. (2012). Microbial community analysis of Korean soybean pastes by next-generation sequencing. *International Journal of Food Microbiology*, *155*, 36–42. https://doi.org/10.1016/j.ijfoodmicro.2012.01.013

Nguyen, D. T. L., Van Hoorde, K., Cnockaert, M., de Brandt, E., de Bruyne, K., Le, B. T., & Vandamme, P. (2013). A culture-dependent and -independent approach for the identification of lactic acid bacteria associated with the production of nem chua, a Vietnamese fermented meat product. *Food Research International*, *50*, 232–240. https://doi.org/10.1016/j.foodres.2012.09.029

Nishito, Y., Osana, Y., Hachiya, T., Popendorf, K., Toyoda, A., Fujiyama A. … Sakakibara Y. (2010). Whole genome assembly of a natto production strain *Bacillus subtilis* natto from very short read data. *BMC Genomics*, *11*, 243. https://doi.org/10.1186/1471-2164-11-243

Nout, M. J., & Kiers, J. L. (2005). Tempe fermentation, innovation and functionality: Update into the third millenium. *Journal of Applied Microbiology*, *98*, 789–805. Retrieved from htts://doi.org/10.1111/j.1365-2672.2004.02471.x

Nout, M. J. R., & Sarkar, P. K. (1999). Lactic acid food fermentation in tropical climates In W. N. Konings, O. P. Kuipers, & J. H. J.H. In 't Veld (Eds.), *Lactic acid bacteria: Genetics, metabolism and applications* (pp. 395–401). Dordrecht: Springer. https://doi.org/10.1023/A:1002066306013

OECD. (2018). Table A.5 - World dairy projections: Butter and cheese. OECD-FAO Agricultural Outlook 2018–2027. OECD Publishing, Paris. https://doi.org/10.1787/agr_outlook-2018-table112-en.

Oguntoyinbo, F. A. (2014). Safety challenges associated with traditional foods of West Africa. *Food Reviews International*, *30*, 338–358. https://doi.org/10.1080/87559129.2014.940086

Oguntoyinbo, F. A., & Dodd, C. E. R. (2010). Bacterial dynamics during the spontaneous fermentation of cassava dough in *gari* production. *Food Control*, *21*, 306–312. https://doi.org/10.1016/j.foodcont.2009.06.010

Oguntoyinbo, F.A., Sanni A. I., Franz, C.M.A.P., & Holzapfel, W.H. (2007). *In vitro* fermentation studies for selection and evaluation of Bacillus strains as starter cultures for the production of okpehe, a traditional African fermented condiment. *International Journal of Food Microbiology*, *113*, 208–218. https://doi.org/10.1016/j.ijfoodmicro.2006.07.006

Olasupo, N. A., Odunfa, S. A., & Obayori, O. S. (2010). Ethnic African fermented foods. In J. P. Tamang & K. Kailasapathy (Eds.), *Fermented foods and beverages of the world* (pp. 323–352). New York, NY: CRC Press.

Ouoba, L., Cantor, M., Diawara, B., Traoré, A., & Jakobsen, M. (2003a). Degradation of African locust bean oil by *Bacillus subtilis* and *Bacillus pumilus* isolated from soumbala, a fermented African locust bean condiment. *Journal of Applied Microbiology*, *95*, 868–873. https://doi.org/10.1046/j.1365-2672.2003.02063.x

Ouoba, L., Rechinger, K., Barkholt, V., Diawara, B., Traore, A., & Jakobsen, M. (2003b). Degradation of proteins during the fermentation of African locust bean (*Parkia biglobosa*) by strains of *Bacillus subtilis and Bacillus pumilus* for production of Soumbala. *Journal of Applied Microbiology*, *94*, 396–402. https://doi.org/10.1046/j.1365-2672.2003.01845.x

Ouoba, L., Diawara, B., Wk, A. A., Traore, A., & Moller, P. (2004). Genotyping of starter cultures of *Bacillus subtilis* and *Bacillus pumilus* for fermentation of African locust bean (*Parkia biglobosa*) to produce Soumbala. *International Journal of Food Microbiology*, *90*, 197–205. https://doi.org/10.1016/S0168-1605(03)00302-7

Ouoba, L., Diawara, B., Annan, N., Poll, L., & Jakobsen, M. (2005). Volatile compounds of Soumbala, a fermented African locust bean (*Parkia biglobosa*) food condiment. *Journal of Applied Microbiology*, *99*, 1413–1421. https://doi.org/10.1111/j.1365-2672.2005.02722.x

Ouoba, L. I. I., Diawara, B., Christensen, T., Dalgaard Mikkelsen, J., & Jakobsen, M. (2007a). Degradation of polysaccharides and non-digestible oligosaccharides by *Bacillus subtilis* and *Bacillus pumilus* isolated from Soumbala, a fermented African locust bean (*Parkia biglobosa*) food Condiment. *European Food Research and Technology*, *224*, 689–694. https://doi.org/10.1007/s00217-006-0359-0

Ouoba, L. I. I., Diawara, B., Jespersen, L., & Jakobsen, M. (2007b). Antimicrobial activity of *Bacillus subtilis* and *Bacillus pumilus* during the fermentation of African locust bean (*Parkia biglobosa*) for Soumbala production. *Journal of Applied Microbiology*, *102*, 963–970. https://doi.org/10.1111/j.1365-2672.2006.03156.x

Ouoba, L., Parkouda, C., Diawara, B., Scotti, C., & Varnam, A. (2008). Identification of *Bacillus* spp. from Bikalga, fermented seeds of *Hibiscus sabdariffa*: Phenotypic and genotypic characterization. *Journal of Applied Microbiology*, *104*, 122–131. https://doi.org/10.1111/j.1365-2672.2007.03550.x

Ouoba, L. I., Nyanga-Koumou, C. A., Parkouda, C., Sawadogo, H., Kobawila, S. C., Keleke, S., … Sutherland, J. P. (2010). Genotypic diversity of lactic acid bacteria isolated from African traditional alkaline-fermented foods. *Journal of Applied Microbiology*, *108*, 2019–2029. https://doi.org/10.1111/j.1365-2672.2009.04603.x

Oyewole, O. B., Olatunji, O. O., & Odunfa, S. A. (2004). A process technology for conversion of dried cassava chips into 'gari'. *Nigeria Food Journal*, *22*, 65–76. https://doi.org/10.4314/nifoj.v22i1.33570

Papalexandratou, Z., Vrancken, G., De Bruyne, K., Vandamme, P., & De Vuyst, L. (2011). Spontaneous organic cocoa bean box fermentations in Brazil are characterized by a restricted species diversity of lactic acid bacteria and acetic acid bacteria. *Food Microbiology*, *28*, 1326–1338. https://doi.org/10.1016/j.fm.2011.06.003

Parente, E., & Cogan, T.M. (2004). Starter cultures: general aspects, in: *Cheese: Chemistry, Physics and Microbiology*. Fox, P. O. ed., 3rd edition, Elsevier: Oxford, 123–147. https://doi.org/10.1016/S1874-558X(04)80065-4

Parks, D., Chung, I. H., Lee, I. K., Kim, E. J., Niraula, S., & Chang, W. S. (2019). Genome sequence of *Bacillus subtilis* natto VK161, a novel strain that produces vitamin K2. *Microbiology Resource Announcements*, *8*, e00444–19. https://doi.org/10.1128/MRA.00444-19

Park, S. E., Seo, S. H., Kim, E. J., Byun, S., Na, C. S., & Son, H. S. (2019). Changes of microbial community and metabolite in kimchi inoculated with different microbial community starters. *Food Chemistry*, *274*, 558–565. https://doi.org/10.1016/j.foodchem.2018.09.032

Parker, M., Zobrist, S., Donahue, C., Edick, C., Mansen, K., Hassan Zade Nadjari, M., … Kort, R. (2018). Naturally fermented milk from northern Senegal: Bacterial community composition and probiotic enrichment with *Lactobacillus rhamnosus*. *Frontiers in Microbiology*, *9*, 2218. https://doi.org/10.3389/fmicb.2018.02218

Parkouda, C., Nielsen, D. S., Azokpota, P., Ivette Irène Ouoba, L., Amoa-Awua, W. K., Thorsen, L., … Jakobsen, M. (2009). The microbiology of alkaline-fermentation of indigenous seeds used as food condiments in Africa and Asia. *Critical Reviews in Microbiology*, *35*, 139–156. https://doi.org/10.1080/10408410902793056

Pasqualone, A. (2018). Traditional flat breads spread from the Fertile Crescent: Productive process and history of baking systems. *Journal of Ethnic Foods*, *51*, 10–19. https://doi.org/10.1016/j.jef.2018.02.002

Pederson, C. S. (1979). *Microbiology of food fermentations* (2nd edition). Westport, CT: AVI.

Pederson, C. S., & Albury, M. N. (1969). The sauerkraut fermentation. *Food Technology*, *8*, 1–5.

Peng, Q., Jiang, S., Chen, J., Ma, C., Huo, D., Shao, Y., & Zhang, J. (2018). Unique microbial diversity and metabolic pathway features of fermented vegetables from Hainan, China. *Frontiers in Microbiology*, *9*, 399. https://doi.org/10.3389/fmicb.2018.00399

Peres, C. M., Peres, C., Hernández-Mendoza, A., & Malcata, F. X. (2012). Review on fermented plant materials as carriers and sources of potentially probiotic lactic acid bacteria–with an emphasis on table olives. *Trends in Food Science & Technology*, *26*, 31–42. https://doi.org/10.1016/j.tifs.2012.01.006

Plavsic, D., Okanovic, D., Gubic, J., & Njezic, Z. (2015). Microbiological and chemical evaluation of dried smoked meat product. *Procedia Food Science*, *5*, 239–242. https://doi.org/10.1016/j.profoo.2015.09.061

Prakash, O. (1961). *Food and drinks in ancient India*. Delhi, India: Munshi Ram Monohar Lal.

Prajapati, J. B., & Nair, B. M. (2003). The history of fermented foods. In R. Farnworth. *Handbook of fermented functional foods* (pp. 1–25). New York, NY: CRC Press.

Puerari, C., Magalhães-Guedes, K. T., & Schwan, R. F. (2015). Physicochemical and microbiological characterization of chicha, a rice-based fermented beverage produced by Umutina Brazilian Amerindians. *Food Microbiology*, *46*, 210–217. https://doi.org/10.1016/j.fm.2014.08.009

Rai, A. K., Tamang, J. P., & Palni, U. (2010). Microbiological studies of ethnic meat products of the Eastern Himalayas. *Meat Science*, *85*, 560–567. https://doi.org/10.1016/j.meatsci.2010.03.006

Rai, R., Shangpliang, H. N. J., & Tamang, J. P. (2016). Naturally fermented milk products of the Eastern Himalayas. *Journal of Ethnic Foods*, *3*, 270–275.

Rantsiou, K., & Cocolin, L. (2008). Fermented Meat Products. In L. Cocolin, & D. Ercolini (Eds.), *Molecular techniques in the microbial ecology of fermented eoods* (pp. 91–118). New York, NY: Springer.

Rasic, J. L., & Kurmann, J. A. (1978). *Yoghurt - scientific grounds, technology, manufacture and preparations*. Copenhagen: Technical Dairy Publishing House.

Rejano, L., Montaño, A., Casado, F. J., Sánchez, A. H., & de Castro, A. (2010). Table olives: Varieties and variations. In V. R. Preedy & R. R. Watson (Eds.), *Olives and olive oil in health and disease prevention* (pp. 5–15). Academic Press.

Renfrew, J. W. (1999). Palaeoethnobotany and the archaeology of wine. In J. Robinson (Ed.), *The Oxford companion to wine* (2nd edition, pp. 508–509). Oxford, UK: Oxford University Press.

Rezac, S., Kok, C. R., Heermann, M., & Hutkins, R. (2018). Fermented foods as a dietary source of live organisms. *Frontiers in Microbiology*, *9*, 1785. https://doi.org/10.3389/fmicb.2018.01785

Robinson, R. K., & Tamime, A. Y. (2006). Types of Fermented Milks. In A. Y. Tamime (Ed.), *Fermented milks* (pp. 1–10). Hoboken, NJ: Wiley.

Prado, M. R., Blandón, L. M., Vandenberghe, L. P., Rodrigues, C., Castro, G. R., Thomaz-Soccol, V., & Soccol, C. R. (2015). Milk kefir: Composition, microbial cultures, biological activities, and related products. *Frontiers in Microbiology*, *6*, 1177. https://doi.org/10.3389/fmicb.2015.01177

Ruddle, K. (1993). The availability and supply of fish for fermentation in Southeast Asia. In C. H. Lee, Steinkraus K.H., & P. J. Alan Reilly (Eds.), *Fish fermentation technology* (pp. 45–84). Tokyo: United Nations University Press.

Saithong, P., Panthavee, W., Boonyaratanakornkit, M., & Sikkhamondhol, C. (2010). Use of a starter culture of lactic acid bacteria in *plaasom*, a Thai fermented fish. *Journal of Bioscience and Bioengineering*, *110*, 553–557.

Salampessy, J., Kailasapathy, K., & Thapa, N. (2010). Fermented fish products. In J. P. Tamang & K. Kailasapathy (Eds.), *Fermented foods and beverages of the world* (pp. 289–307). New York, NY: CRC Press.

Salque, M., Bogucki, P. I., Pyzel, J., Sobkowiak-Tabaka, I., Grygiel, R., Szmyt, M., & Evershed, R.P. (2012). Earliest evidence for cheese making in the sixth millennium BC in northern Europe. *Nature*, *493*, 522–525. https://doi.org/10.1038/nature11698

Samuel, D. (2002). Bread in archaeology. *Civilisations*, *49*, 28–36.

Sánchez, M. M., Stavropoulou, D. A., & Leroy, F. (2017). Exploring the metabolic heterogeneity of coagulase-negative staphylococci to improve the quality and safety of fermented meats: A review. *International Journal of Food Microbiology*, *247*, 24–37. https://doi.org/10.1016/j.ijfoodmicro.2016.05.021

Schillinger, U., Ban-Koffi, L., & Franz, C. M. A.P. (2010). Tea, coffee and cacao. In J. P. Tamang & K. Kailasapathy (Eds.), *Fermented foods and beverages of the world* (pp. 353–375). New York, NY: CRC Press.

Sealey, P. R., & Tyers, P. A. (1989). Olives from Roman Spain: A unique amphora find in British waters. *The Antiquaries Journal*, *69*, 54–72.

Segers, M. E., & Lebeer, S. (2014). Towards a better understanding of *Lactobacillus rhamnosus* GG–host interactions. *Microbial Cell Factories*, *13*(Supplement 1), S7. https://doi.org/10.1186/1475-2859-13-S1-S7

Seol, D., Jhang, S. Y., Kim, H., Kim, S. Y., Kwak, H. S., Kim, S. H., … Kwak, W. (2019). Accurate and strict identification of probiotic species based on coverage of whole-metagenome shotgun sequencing data. *Frontiers in Microbiology*, *10*, 1683. https://doi.org/10.3389/fmicb.2019.01683

Serra, J. L., Moura, F. G., de Melo Pereira, G. V., Soccol, C. R., Rogez, H., & Darnet, S. (2019). Determination of the microbial community in Amazonian cocoa bean fermentation by Illumina-based metagenomic sequencing. *LWT*, *106*, 229–239. https://doi.org/10.1016/j.lwt.2019.02.038

Sha, S. P., Jani, K., Sharma, A., Anupma, A., Pradhan, P., Shouche, Y., & Tamang, J. P. (2017). Analysis of bacterial and fungal communities in *Marcha* and *Thiat*, traditionally prepared amylolytic starters of India. *Scientific Reports*, *7*, 10967 https://doi.org/10.1038/s41598-017-11609-y

Sha, S. P., Suryavanshi, M. S., & Tamang, J. P. (2019). Mycobiome diversity in traditionally prepared starters for alcoholic beverages in India by high-throughput sequencing method. *Frontiers in Microbiology*, *10*, 348. https://doi.org/10.3389/fmicb.2019.003482237

Sha, S. P., Suryavanshi, M. S., Jani, K., Sharma, A., Shouche, Y., & Tamang, J. P. (2018). Diversity of yeasts and molds by culture-dependent and culture-independent methods for mycobiome surveillance of traditionally prepared dried starters for the production of Indian alcoholic beverages. *Frontiers in Microbiology*, *9*, 2237. https://doi.org/10.3389/fmicb.2018.02237

Shangpliang, H. N. J., Rai, R., Keisam, S., Jeyaram, K., & Tamang, J. P. (2018). Bacterial community in naturally fermented milk products of Arunachal Pradesh and Sikkim of India analysed by high-throughput amplicon sequencing. *Science Reports*, *8*, 1532. https://doi.org/10.1038/s41598-018-19524-6

Shi, Z., Zhang, Y., Phillips, G. O., & Yang, G. (2014). Utilization of bacterial cellulose in food. *Food Hydrocolloids*, *35*, 539–545.

Shin, S. K., Kwon, J. H., Jeong, T. J., Jeon, S. M., Choi, J. Y. & Choi, M. S. (2011). Supplementation of *Cheonggukjang* and Red Ginseng *Cheonggukjang* can improve plasma lipid profile and fasting blood glucose concentration in subjects with impaired fasting glucose. *Journal of Medicinal Food*, *14*, 108–113.

Shurtleff, W., & Aoyagi, A. (2010). History of soybeans and soyfoods in South Asia/Indian subcontinent (1656-2010): Extensively annotated, bibliography and sourcebook. Retrieved from www.soyinfocenter.com/books

Smit, G., Smit, B. A., & Engels, W. J. (2005). Flavour formation by lactic acid bacteria and biochemical flavour profiling of cheese products. *FEMS Microbiology Reviews*, *29*, 591–610. https://doi.org/10.1016/j.fmrre.2005.04.002

Solieri, L., & Giudici, P. (2008). Yeasts associated to traditional balsamic vinegar: Ecological and technological features. *International Journal of Food Microbiology*, *125*, 36–45.

Spitaels, F., Wieme, A. D., Janssens, M., Aerts, M., Van Landschoot, A., De Vuyst, L., & Vandamme, P. (2015). The microbial diversity of an industrially produced lambic beer shares members of a traditionally produced one and reveals a core microbiota for lambic beer fermentation. *Food Microbiology*, *49*, 23–32. https://doi.org/10.1016/j.fm.2015.01.008

Steinkraus, K. H. (1994). Nutritional significance of fermented foods. *Food Research International*, *27*, 259–267.

Steinkraus, K. H. (1996). *Handbook of indigenous fermented food* (2nd edition). New York, NY: Marcel Dekker, Inc.

Steinkraus, K. H. (2002). Fermentations in world food processing. *Comprehensive Reviews in Food Science and Food Safety*, *1*(1). 23–32.

Sulaiman, J., Gan, H. M., Yin, W. F., & Chan, K. G. (2014). Microbial succession and the functional potential during the fermentation of Chinese soy sauce brine. *Frontiers in Microbiology*, *5*, 556. https://doi.org/10.3389/fmicb.2014.00556

Surono, I. S. (2016). Ethnic fermented foods and beverages of Indonesia. In J. P. Tamang (Ed.), *Ethnic fermented foods and alcoholic beverages of Asia* (pp. 341–382). New Delhi, India: Springer Nature.

SUSFOOD (2013). Definitions. SUStainable FOOD production and consumption (SUSFOOD). Retrieved from https://www.susfood-era.net/index.php?index=30

Sybesma, W., Molenaar, D., van IJcken, W., Venema, K., & Kort, R. (2013). Genome instability in *Lactobacillus rhamnosus* GG. *Applied and Environmental Microbiology*, *79*, 2233–2239.

Tahir, A., Anwar, M., Mubeen, H., & Raza, S. (2018). Evaluation of physicochemical and nutritional contents in soybean fermented food tempeh by *Rhizopus oligosporus*. *Journal of Advances in Biology & Biotechnology*, *17*, 1–9. https://doi.org/10.9734/JABB/2018/26770

Tamang, B., & Tamang, J. P. (2010). *In situ* fermentation dynamics during production of *gundruk* and *khalpi*, ethnic fermented vegetables products of the Himalayas. *Indian Journal of Microbiology*, *50*(1), S93–S98.

Tamang, B., Tamang, J. P., Schillinger, U., Franz, C. M. A.P., Gores, M., & Holzapfel, W. H. (2008). Phenotypic and genotypic identification of lactic acid bacteria isolated from ethnic fermented tender bamboo shoots of North East India. *International Journal of Food Microbiology*, *121*, 35–40.

Tamang, J. P. (2015). Naturally fermented ethnic soybean foods of India. *Journal of Ethnic Foods*, *2*, 8–17.

Tamang, J. P. (2010a). Diversity of fermented foods. In J. P. Tamang & K. Kailasapathy (Eds.), *Fermented foods and beverages of the world* (pp. 41–84). New York, NY: CRC Press.

Tamang, J. P. (2010b). *Himalayan fermented foods: Microbiology, nutrition, and ethnic values*. New York, NY: CRC Press.

Tamang, J. P., & Fleet, G. H. (2009). Yeasts diversity in fermented foods and beverages, In T. Satyanarayana & G. Kunze (Eds.), *Yeasts biotechnology: Diversity and applications* (pp. 169–198). New York, NY: Springer.

Tamang, J. P., Holzapfel, W. H., & Watanabe, K. (2016a). Diversity of microorganisms in global fermented foods and beverages. *Frontiers in Microbiology*, *7*, 377. https://doi.org/10.3389/fmicb.2016.00377

Tamang, J. P., Shin, D. H., Jung, S. J., & Chae, S. W. (2016b). Functional properties of microorganisms in fermented foods. *Frontiers in Microbiology*, *7*, 578. https://doi.org/10.3389/fmicb.2016.00578

Tamang, J. P., & Samuel, D. (2010). Dietary culture and antiquity of fermented foods and beverages. In J. P. Tamang & K. Kailasapathy (Eds.), *Fermented foods and beverages of the world* (pp. 1–40). New York, NY: CRC Press.

Tamang, J. P., Thapa, S., Dewan, S., Jojima, Y., Fudou, R., & Yamanaka, S. (2002). Phylogenetic analysis of *Bacillus* strains isolated from fermented soybean foods of Asia: *Kinema, chungkokjang* and *natto*. *Journal of Hill Research*, *15*, 56–62.

Tamang, J. P., Tamang, B., Schillinger, U., Franz, C. M. A.P., Gores, M., & Holzapfel, W. H. (2005). Identification of predominant lactic acid bacteria isolated from traditional fermented vegetable products of the Eastern Himalayas. *International Journal of Food Microbiology*, *105*, 347–356. https://doi.org/10.1016/j.ijfoodmicro.2005.04.024

Tamang, J. P., Tamang, B., Schillinger, U., Guigas, C., & Holzapfel, W. H. (2009). Functional properties of lactic acid bacteria isolated from ethnic fermented vegetables of the Himalayas. *International Journal of Food Microbiology*, *135*, 28–33. https://doi.org/10.1016/j.ijfoodmicro.2009.07.016

Tamime, A. Y., & Robinson, R. K. (2007). *Yoghurt science and technology*. Cambridge, UK: Woodhead Publishing Ltd.

Tanasupawat, S., Hashimoto, Y., Ezaki, T., Kozaki, M., & Komagata, K. (1991). Identification of *Staphylococcus carnosus* strains from fermented fish and soy sauce mash. *Journal of General and Applied Microbiology*, *37*, 479–494. https://doi.org/10.2323/jgam.37.479

Tanasupawat, S., Pakdeeto, A., Thawai, C., Yukphan, P., & Okada, S. (2007). Identification of lactic acid bacteria from fermented tea leaves (miang) in Thailand and proposals of *Lactobacillus thailandensis* sp. nov., *Lactobacillus camelliae* sp.nov., and *Pediococcus siamensis* sp.nov. *Journal of General and Applied Microbiology*, *53*, 7–15. https://doi.org/10.2323/jgam.53.7

Teoh, A. L., Heard, G., & Cox, J. (2004). Yeasts ecology of Kombucha fermentation. *International Journal of Food Microbiology*, *95*, 119–126. https://doi.org/10.1016/j.ijfoodmicro.2003.12.020

Thapa, N., Pal, J., & Tamang, J. P. (2004). Microbial diversity in *ngari, hentak* and *tungtap*, fermented fish products of Northeast India. *World Journal of Microbiology and Biotechnology*, *20*, 599–607. https://doi.org/10.1023/B:WIBI.0000043171.91027.7e

Thapa, N., Pal, J., & Tamang, J. P. (2006). Phenotypic identification and technological properties of lactic acid bacteria isolated from traditionally processed fish products of the Eastern Himalayas. *International Journal of Food Microbiology*, *107*, 33–38. https://doi.org/10.1016/j.ijfoodmicro.2005.08.009

Thapa, N., Pal, J., & Tamang, J. P. (2007). Microbiological profile of dried fish products of Assam. *Indian Journal of Fisheries*, *54*, 121–125.

Thongthai, C., & Gildberg, A. (2005). Asian fish sauce as a source of nutrition. In J. Shi, C-T. Ho, & F. Shahidi (Eds.), *Asian functional foods* (pp. 215–265). New York, NY: Taylor & Francis.

Thongthai, C., & Suntinanalert, P. (1991). Halophiles in Thai fish sauce (*Nam pla*). In F. Rodriguez-Valera (Ed.), *General and applied aspects of halophilic microorganisms* (pp. 381–388). New York, NY: Plenum Press.

Toba, T., Kotani, T., & Adachi, S. (1991). Capsular polysaccharide of a slime-forming *Lactococcus lactis* ssp. *cremoris* LAPT 3001 isolated from Swedish fermented milk 'långfil'. *International Journal of Food Microbiology*, *12*, 167–171. https://doi.org/10.1016/0168-1605(91)90066-X

Tolhurst, G., Heffron, H., Lam, Y. S., Parker, H. E., Habib, A. M., Diakogiannaki, E., … Gribble, F. M. (2012). Short-chain fatty acids stimulate glucagon-like peptide-1 secretion via the g-protein-coupled receptor FFAR2. *Diabetes*, *61*, 364–371. https://doi.org/10.2337/db11-1019

Tyn, M. T. (1993). Trends of fermented fish technology in Burma. In C. H. Lee, Steinkraus K.H., & P. J. Alan Reilly (Eds.), *Fish fermentation technology* (pp. 129–153). Tokyo: United Nations University Press.

Valamoti, S. M. (2018). Brewing beer in wine country? First archaeobotanical indications for beer making in Early and Middle Bronze Age Greece. *Vegetation History and Archaeobotany*, *27*, 611–625.

Vong, W. C., & Liu, S.-Q. (2016). Biovalorisation of okara (soybean residue) for food and nutrition. *Trends in Food Science & Technology*, *52*, 139–147. https://doi.org/10.1016/j.tifs.2016.04.011

Waché, Y., Do, T. L., Thi-Bao-Hoa, D., Do, T. Y., Haure, M., Ho, P. H., … Chu-Ky, S. (2018). Prospects for food fermentation in South-East Asia, topics from the tropical fermentation and biotechnology network at the end of the AsiFood Erasmus+ Project. *Frontiers in Microbiology*, *9*, 2278. https://doi.org/10.3389/fmicb.2018.02278

Walsh, A. M., Crispie, F., O'Sullivan, O., Finnegan, L., Claesson, M. J., & Cotter, P. D. (2018). Species classifier choice is a key consideration when analysing low-complexity food microbiome data. *Microbiome*, *6*, 50. https://doi.org/10.1186/s40168-018-0437-0

Walsh, A. M., Crispie, F., Kilcawley, K., O'Sullivan, O., O'Sullivan, M. G., Claesson, M. J., & Cotter, P. D. (2016). Microbial succession and flavor production in the fermented dairy beverage kefir. *Msystems*, *1*, e00052–16. https://doi.org/10.1128/mSystems.00052-16

Wang, J., &. Fung, D. Y. C. (1996). Alkaline-fermented foods: A review with emphasis on pidan fermentation. *Critical Review in Microbiology*, *22*, 101–138. https://doi.org/10.3109/10408419609106457

Wang, X., Du, H., Zhang, Y., & Xu, Y. (2018). Environmental microbiota drives microbial succession and metabolic profiles during Chinese liquor fermentation. *Applied and Environment Microbiology*, *84*, e02369–17.https://doi.org/10.1128/AEM.02369-17

Wang, X., Xiao, J., Jia, Y., Pan, Y., & Wang, Y. (2018). *Lactobacillus kefiranofaciens*, the sole dominant and stable bacterial species, exhibits distinct morphotypes upon colonization in Tibetan kefir grains. *Heliyon*, *4*, e00649. https://doi.org/10.1016/j.heliyon.2018.e00649

Watanabe, K., Makino, H., Sasamoto, M., Kudo, Y., Fujimoto, J., & Demberel, S. (2009). *Bifidobacterium mongoliense* sp. nov., from *airag*, a traditional fermented mare's milk product from Mongolia. *International Journal of Systematic and Evolutionary Microbiology*, *59*, 1535–1540. https://doi.org/10.1099/ijs.0.006247-0

Watanaputi, S. P., Chanyavongse, R., Tubplean, S., Tanasuphavatana, S., & Srimahasongkhraam, S. (1983). Microbiological analysis of Thai fermented foods. *Journal of the Graduate School, Chulalongkorn University*, *4*, 11–24.

Weckx, S., Van Kerrebroeck, S., & De Vuyst, L. (2019). Omics approaches to understand sourdough fermentation processes. *International Journal of Food Microbiology*, *302*, 90–102.

Wegley, L., Edwards, R., Rodriguez-Brito, B., Liu, H., & Rohwer, F. (2007). Metagenomic analysis of the microbial community associated with the coral Porites astreoides. *Environmental Microbiology*, *9*, 2707–2719. https://doi.org/10.1111/j.1462-2920.2007.01383.x

Westerik, N., Wacoo, A. P., Sybesma, W., & Kort, R. (2016). Novel production protocol for small-scale manufacture of probiotic fermented foods. *JoVE (Journal of Visualized Experiments)*, *115*, e54365–e54365. https://doi.org/10.3791/54365

WHO, (2009). Diarrhoea: Why children are still dying and what can be done. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/44174/9789241598415_eng.pdf;jsessionid=30BE99BB9F8BA7D1156BF6FBE89084BB?sequence=1

Wilkins, J. M., & Hill, S. (2006). *Food in the ancient world*. Oxford, UK: Blackwell.

Wilson, H. (1999). Origins of viticulture. In *The Oxford companion to wine* (2nd edition, pp. 505–506). J. Robinson (Ed.), Oxford, UK: Oxford University Press.

Wolfe, B. E., Button, J. E., Santarelli, M., & Dutton, R. J. (2014). Cheese rind communities provide tractable systems for in situ and *in vitro* studies of microbial diversity. *Cell*, *158*, 422–433. https://doi.org/10.1016/j.cell.2014.05.041

Wolfe, B. E., & Dutton, R. J. (2015). Fermented foods as experimentally tractable microbial ecosystems. *Cell*, *161*, 49–55. https://doi.org/10.1016/j.cell.2015.02.034

Wu, Y. C., Kimura, B., & Fujii, T. (2000). Comparison of three culture methods for the identification of *Micrococcus* and *Staphylococcus* in fermented squid shiokara. *Fisheries Science*, *66*, 142–146. https://doi.org/10.1046/j.1444-2906.2000.00021.x

Yan, Y., Qian, Y., Ji, F., Chen, J., & Han, B. (2013). Microbial composition during Chinese soy sauce *koji*-making based on culture dependent and independent methods. *Food Microbiology*, *34*, 189–195. https://doi.org/10.1016/j.fm.2012.12.009

Yanagisawa, Y., & Sumi, H. (2005). Natto bacillus contains a large amount of water-soluble vitamin K (menaquinone-7). *Journal of Food Biochemistry*, *29*, 267–277. https://doi.org/10.1111/j.1745-4514.2005.00016.x

Yegna Narayan Aiyar, A. K. (1953). Dairying in ancient India. *Indian Dairyman*, *5*, 77–83.

Yi, Z., Jin, Y., Xiao, Y., Chen, L., Tan, L., Du, A., … Zhao, H. (2019). Unraveling the contribution of high temperature stage to jiang-flavor Daqu, a liquor starter for production of Chinese jiang-flavor baijiu, with special reference to metatranscriptomics. *Frontiers in Microbiology*, *10*, 472. https://doi.org/10.3389/fmicb.2019.00472

Yokoysuka, T. (1985). Fermented protein foods in the orient, with emphasis on shoyu and miso in Japan. In B. J. B. Wood (Ed.), *Microbiology of fermented food* (Vol. 1, pp. 197–247). New York, NY: Elsevier Applied Science Publishers.

Zakpaa, H. D., Imbeah, C. M., & Mak-Mensah, E. E. (2009). Microbial characterization of fermented meat products on some selected markets in the Kumasi metropolis, Ghana:. *African Journal of Food Science*, *3*(11), 340–346.

Zhang, J., Wang, Xiaoru, Huo, Dongxue, Li, Wu, Hu, Qisong, Xu, Chuanbiao, … Li, C. (2016). Metagenomic approach reveals microbial diversity and predictive microbial metabolic pathways in *Yucha*, a traditional Li fermented food. *Scientific Reports*, *6*, 32524. https://doi.org/10.1038/srep32524

Zhang, J. H., Tatsumi, E., Fan, J. F., & Li, L. T. (2007). Chemical components of *Aspergillus*-type Douchi, a Chinese traditional fermented soybean product, change during the fermentation process. *International Journal of Food Science and Technology*, *42*, 263–268. https://doi.org/10.1111/j.1365-2621.2005.01150.x

Zhu, Y., Zhang, F., Zhang, C., Yang, L., Fan, G., Xu, Y., … Li, X. (2018). Dynamic microbial succession of Shanxi aged vinegar and its correlation with flavor metabolites during different stages of acetic acid fermentation. *Scientific Reports*, *8*, 8612. https://doi.org/10.1038/s41598-018-26787-6

How to cite this article: Tamang JP, Cotter P, Endo A, et al. Fermented foods in a global age: East meets West. *Compr Rev Food Sci Food Saf*. 2020;1–34. https://doi.org/10.1111/1541-4337.12520