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Health Benefits of Fermented Foods and Beverages

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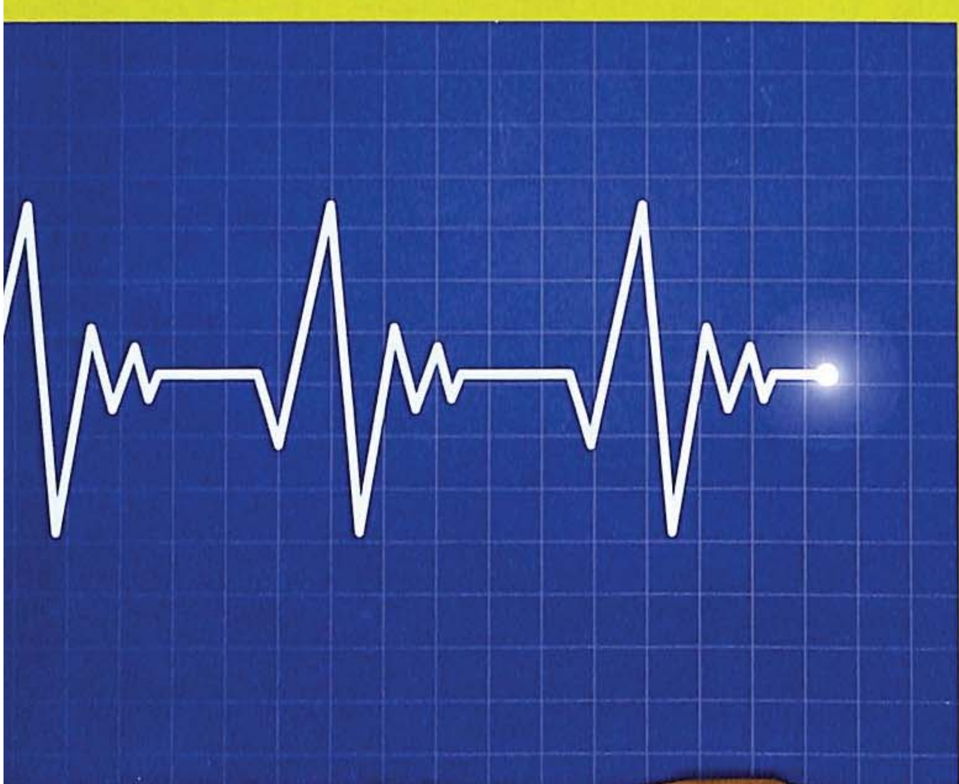
JYOTI PRAKASH TAMANG



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Contents

Preface

Fermented foods contribute an important part of the diet of industrialized countries, and an equally essential role in nutrition in developing countries. More than 5000 varieties of common and uncommon fermented foods and alcoholic beverages are consumed in the world. About 80% of global fermented foods are naturally fermented by both cultivable and uncultivable microorganisms. The application of molecular and modern identification tools through culture-dependent and culture-independent techniques including next-generation sequence techniques has thrown new light on the diversity of a number of previously unknown and uncultivable microorganisms in naturally fermented foods. Ethnic food fermentations represent a precious cultural heritage in most regions, and harbor a huge genetic potential of valuable but hitherto undiscovered strains.

The sustainable use of microorganisms in food fermentation is based on an interrelationship between indigenous knowledge of food fermentation, modern expertise and information, a basic understanding of the microbial background of fermentation and of good hygienic practices (GHP), some experience of handling microbial cultures, and conservation of microbial strains. The diversity of functional microorganisms in fermented foods and beverages consists of bacteria, yeasts, and fungi. Microorganisms establish relevant substrates for survival and produce bioactive compounds that enrich the human diet, thereby benefiting the health of mankind. Ethnic fermented foods of the world are considered to be a means to preserve microbial diversity *ex situ*; they are custodians of microbial diversity and play a key role in the storage and supply of authentic reference material for research and development.

The most remarkable aspects of fermented foods are their biological functions that enhance several health benefits to consumers due to the functional microorganisms associated with them. Functional properties of fermented foods are acidification, bio-preservation, bio-transformation of bland substrates, bio-enrichment of nutritional value, bio-degradation of undesirable compounds, probiotic properties, bio-production of peptides, enzymes, antimicrobial properties, protective cultures, production of isoflavones, saponin and polyglutamic acid, and antioxidant activity. The health-promoting benefits of fermented foods and beverages are prevention of cardiovascular disease, cancer, hepatic disease, gastrointestinal disorders and inflammatory bowel disease; protection from hypertension, thrombosis, osteoporosis, allergic reactions, diabetes, from spoilage and toxic pathogens and synthesis of nutrient and bioavailability; reduction of obesity; increased immunity; alleviation of lactose intolerance; antiaging effects; and therapeutic values/medicinal values. Today, some ethnic fermented foods and alcoholic beverages are commercialized and marketed globally as health foods, functional foods, therapeutic foods, nutraceuticals, or health foods/drinks. Increased understanding of the viability of probiotic bacteria, interactions between gut microbiota, diet, and the host will open up new possibilities of producing new ingredients for nutritionally optimized foods that promote consumer health through microbial activities in the gut. Introduction of new fermented food products containing friendly/good bacteria will emerge such as cereals, energy bars, cheese, juices, disease-specific medical foods and infant foods. However, 90% of health-benefiting naturally fermented foods and alcoholic beverages in the world are still produced at home by traditional methods.

This book has 21 chapters covering the health benefits of fermented foods of the world. There is a separate chapter on microorganisms in fermented foods and beverages of the world. We attempted to update and collate information and research carried out on various aspects of health-promoting benefits of fermented foods and beverages. We are grateful to all contributing authors who accepted our invitation to contribute to this book. Some of them are well recognized scientists and researchers with vast experience in the field of fermented foods and beverages. We are happy to bring them all together on the same platform to bring out this book. Our thanks to Nagendra Shah of Hong Kong, Toshirou Nagai of Japan, Dong-Hwa Shin, Han Eung-Soo and Hyun Ju Kim of Korea, Raha Abdul Rahim of Malaysia, Anil Anal of Thailand, Yearul Kabir of Bangladesh, Baltasar Mayo of Spain, Mary Astuti of Indonesia, Ramesh Chandan of the United States, Rintu Banerjee, Rabindra Malik, Rekha Singhal, Prakash Halami, Anu Appaiah, Usha Rani, Kumaraswamy Jeyaram, Santa Ram Joshi, Binaya Nayak, Namrata Thapa, G. Balakrish Nair, Neerja Hajela and Sarath Gopalan—all from different parts of India. We are also grateful to the Taylor & Francis Group, CRC Press for publishing out this comprehensive book and we hope it will be read by researchers, students, teachers, nutritionists, dieticians, food entrepreneurs, agriculturalists, government policy makers, ethnologists, sociologists, and people in the electronic media who are interested in the health benefits of fermented foods and beverages. Although there are hundreds of research articles, review papers, and limited books on fermented foods and beverages, this book *Health Benefits of Fermented Foods and Beverages* is the first of this kind, a compilation of various aspects of functionality and health benefits of fermented foods and beverages of the world.

I dedicate this book to the creators of the indigenous knowledge of traditional food fermentation technologies for putting together both an ocean of knowledge and the basis for research to study indepth molecular nutrition and bioactive compounds in fermented foods and beverages.

Jyoti Prakash Tamang
Gangtok, India

Editor

Professor Jyoti Prakash Tamang has been one of the authorities on global fermented foods and beverages for the last 27 years. He earned a PhD in microbiology from North Bengal University (1992), did postdoctoral research work at the National Food Research Institute, Tsukuba, Japan (1995), and at the Institute of Hygiene and Toxicology, Germany (2002). He was awarded the National Bioscience Award of the Department of Biotechnology by the Government of India in 2005, and the Gourmand Best Cookbook Award in Paris in 2010. He is a fellow of the National Academy of Agricultural Sciences (2012), the Indian Academy of Microbiological Sciences (2010), and the Biotech Research Society of India (2006). He has published more than 120 research papers, and authored several books including *Himalayan Fermented Foods: Microbiology, Nutrition, and Ethnic Values*, and *Fermented Foods and Beverages of the World*, both published by CRC Press, Taylor & Francis Group, USA in 2010. He has one patent, and has mentored several PhD students. He is a member of several prestigious national and international academic groups including the International Yeast Commission and the Asian Federation of Lactic Acid Bacteria, among others. Dr. Tamang is a professor in the Department of Microbiology and also dean of the School of Life Sciences of Sikkim University, a national university in Sikkim. He has served as the first registrar of Sikkim University appointed by the president of India.

Contributors

Sunita Adak
Microbial Biotechnology and Downstream Processing Laboratory
Agricultural and Food Engineering Department
Indian Institute of Technology
Kharagpur, West Bengal, India

Saeed Akhter
Department of Food Science and Technology
Bahauddin Zakariya University
Multan, Pakistan

Leocadio Alonso
Departamento de Microbiología y Bioquímica
Instituto de Productos Lácteos de Asturias (IPLA-CSIC)
Villaviciosa, Asturias, Spain

Anil Kumar Anal
Food Engineering and Bioprocess Technology
Asian Institute of Technology
Pathumthani, Thailand

Anu Appaiah K. A.
Food Microbiology
CSIR-Central Food Technological Research Institute
Mysore, Karnataka, India

Mary Astuti
Universitas Gadjah Mada
Yogyakarta, Indonesia

Lionel In Lian Aun
Department of Biotechnology
UCSI University
Kuala Lumpur, Malaysia

Rintu Banerjee
Microbial Biotechnology and Downstream Processing Laboratory
Agricultural and Food Engineering Department
Indian Institute of Technology
Kharagpur, West Bengal, India

Moumita Bishai
Microbial Biotechnology and Downstream Processing Laboratory
Agricultural and Food Engineering Department
Indian Institute of Technology
Kharagpur, West Bengal, India

Koel Biswas
Department of Biotechnology and Bioinformatics
North-Eastern Hill University
Shillong, Meghalaya, India

Soo-Wan Chae
Clinical Trial Center for Functional Foods
Division of Pharmacology
Chonbuk National University Medical School
Jeonju, South Korea

Ramesh C. Chandan
Global Technologies, Inc.
Minneapolis, Minnesota

Rajen Chettri
Department of Microbiology
School of Life Sciences
Sikkim University (Central University)
Gangtok, Sikkim, India

Hak-Jong Choi
World Institute of Kimchi
Gwangju, South Korea

Son Chu-Ky
School of Biotechnology and Food Technology
Hanoi University of Science and Technology
Hanoi, Vietnam

Shweta Deshaware
Food Engineering and Technology Department
Institute of Chemical Technology
Mumbai, Maharashtra, India

Sheenam Garg
Dairy Microbiology Division
National Dairy Research Institute
Karnal, Haryana, India

Sarath Gopalan
Pushpawati Singhania Research Institute
New Delhi, India

Neerja Hajela
Yakult India Microbiota and Probiotic Science Foundation
New Delhi, India

Prakash M. Halami
Department of Food Microbiology
CSIR-Central Food Technological Research Institute
Mysore, Karnataka, India

Eung Soo Han
World Institute of Kimchi
Gwangju, South Korea

Ashfaque Hossain
Department of Microbiology
College of Medicine
University of Hail
Hail, Saudi Arabia

Swati B. Jadhav
Food Engineering and Technology Department
Institute of Chemical Technology
Mumbai, Maharashtra, India

Kumaraswamy Jeyaram
Microbial Resources Division
Institute of Bioresources and Sustainable Development (IBSD)
Imphal, Manipur, India

Santa Ram Joshi
Microbiology Laboratory
Department of Biotechnology & Bioinformatics
North-Eastern Hill University
Shillong, Meghalaya, India

Su-Jin Jung
Clinical Trial Center for Functional Foods
Division of Pharmacology
Chonbuk National University Medical School
Jeonju, Republic of Korea

Yearul Kabir
Department of Biochemistry and Molecular Biology
University of Dhaka
Dhaka, Bangladesh

Hyun Ju Kim
World Institute of Kimchi
Gwangju, Republic of Korea

Sanath Kumar H.
Post Harvest Technology Department
Central Institute of Fisheries Education (CIFE)
Mumbai, Maharashtra, India

Adelene Song Ai Lian
Department of Cell and Molecular Biology
Universiti Putra Malaysia
Selangor, Malaysia

Foo Hooi Ling
Department of Bioproccess Technology
Universiti Putra Malaysia
Selangor, Malaysia

R. K. Malik
Dairy Microbiology Division
National Dairy Research Institute
Karnal, Haryana, India

Baltasar Mayo
Departamento de Microbiología y Bioquímica
Instituto de Productos Lácteos de Asturias
(IPLA-CSIC)
Villaviciosa, Asturias, Spain

Toshirou Nagai
Genetic Resources Center
National Institute of Agrobiological
Sciences
Tsukuba, Ibaraki, Japan

G. Balakrish Nair
Translational Health Science and Technology
Institute
Gurgaon, Haryana, India

Binaya Bhusan Nayak
Post Harvest Technology Department
Central Institute of Fisheries Education
(CIFE)
Mumbai, Maharashtra, India

Raha Abdul Rahim
Department of Cell and Molecular Biology
Universiti Putra Malaysia
Selangor, Malaysia

Amit Kumar Rai
Regional Center of Institute of Bioresources
and Sustainable Development (RCIBSD)
Tadong, Sikkim, India

Arun Rai
Department of Botany
Sikkim Government College
Tadong, Sikkim, India

Usha Rani M.
Food Microbiology
CSIR-Central Food Technological Research
Institute
Mysore, Karnataka, India

Samira Sarter
CIRAD UMR Qualisud
Hanoi, Vietnam

and

CIRAD, UMR Qualisud
Montpellier, France

Nagendra P. Shah
School of Biological Sciences
The University of Hong Kong
Pokfulam, Hong Kong

Dong-Hwa Shin
Shindonghwa Food Research
Institute
Jeonju, South Korea

Rekha S. Singhal
Food Engineering and Technology
Department
Institute of Chemical Technology
Mumbai, Maharashtra, India

Buddhiman Tamang
Department of Microbiology
School of Life Sciences
Sikkim University (Central University)
Gangtok, Sikkim, India

Jyoti Prakash Tamang
Department of Microbiology
School of Life Sciences
Sikkim University (Central University)
Gangtok, Sikkim, India

Namrata Thapa
Department of Zoology
School of Life Sciences
Sikkim University (Central University)
Gangtok, Sikkim, India

Lakshmishri Upadrasta
Microbial Biotechnology and Downstream Processing Laboratory
Agricultural and Food Engineering Department
Indian Institute of Technology
Kharagpur, West Bengal, India

S. V. N. Vijayendra
Department of Food Microbiology
CSIR-Central Food Technological Research Institute
Mysore, Karnataka, India

Chapter 1

Microorganisms in Fermented Foods and Beverages

Jyoti Prakash Tamang, Namrata Thapa,
Buddhiman Tamang, Arun Rai, and Rajen Chettri

Contents

1.1 Introduction

Traditionally boiled rice is the staple diet with ethnic fermented and nonfermented legume products, vegetables, pickles, fish and meat on the side in the Far East, South and North Asia and the Indian subcontinent excluding western and northern India. In the west and north of India, wheat/barley-based breads/loaves is the staple diet together with milk and fermented milk products, meat and fermented meats. This diet is also followed in West Asia, Europe, North America and in Australia and New Zealand. Sorghum/maize porridges are the main diet with ethnic fermented and nonfermented sorghum/maize/millet, cassava, wild legume seeds, meat and milk products in Africa and South America (Tamang 2012a). Fermented foods are popular throughout the world and in some regions make a significant contribution to the diet of millions of individuals. The fermented food products supply protein, minerals, and other nutrients that add variety and nutritional fortification to otherwise starchy, bland diets.

Fermentation was traditionally a process which enabled the preservation of perishable food and has been used for centuries (www.eolss.net/sample-chapters/c06/e6-34-09-09.pdf; Hansen 2004). The term fermentation comes from the Latin word *fermentum* (to ferment). Throughout the world there are many different types of fermented foods, in which a range of different substrates are metabolized by a variety of microorganisms to yield products with unique and appealing characteristics. Fermented foods and alcoholic beverages are produced from raw materials or substrates of plant or animal origins mostly by natural fermentation or in the case of a few products by microorganisms which modify the substrates biochemically and organoleptically into edible products that are socially acceptable to consumers (Tamang 2010b).

1.1.1 History of Fermented Foods

Methods for fermentation of vegetables might have developed in Asia (Pederson 1979), or in the Mediterranean (Hulse 2004), or in Europe (Tamang and Samuel 2010). Methods for pickling vegetables were well established during the Song dynasty in China (960–1279 AD), and have remained more or less the same to the present day (Tamang and Samuel 2010). *Suau cai*, the ethnic fermented mixed vegetable product of China, was one of the main meals for workers during the construction of the Great Wall of China in 300 BC (Pederson 1979). The history of *kimchi*, a fermented vegetable product of Korea, was traced back to 3–4 AD (Chang 1975). The traditional preparation of *kimchi* was mentioned in someKorean historical documents recorded during 1759–1829 AD (Cheigh 2002). *Sauerkraut* or *sauerkohl* meaning sour cabbage in German was documented in the seventeenth century (Pederson and Albury 1969). Olives were preserved or fermented with various methods in Roman times during 50–150 AD (Sealey and Tyers 1989). The oral history of the origin of some common Himalayan fermented vegetables such as *gundruk*, ethnic fermented leafy vegetables and *sinki*, ethnic fermented radish tap roots were documented by Tamang (2010a).

Bread-making is one of the oldest food processing practices in the food history of human beings. There are ample archaeological remains of tools and installations which were used to make bread in ancient Egypt (Samuel 2002), and descriptions of baking in Roman texts and tombs are available (Curtis 2001). About 250 bakeries were reported to have operated in ancient Rome around 100 BC (Pederson 1979). *Dosa*, the ethnic fermented pancake made from rice and black gram in South India was first noted in the Tamil Sangam literature in India about the sixth century AD (Srinivasa 1930). The traditional preparation of *idli*, an ethnic fermented rice-black gram food of India and Sri Lanka, eaten at breakfast, has been described by the poet Chavundaraya of South India in 1025 AD (Iyengar 1950). *Dhokla*, a fermented mixture of wheat and Bengal gram of western India was first mentioned in 1066 AD (Prajapati and Nair 2003). *Jalebi*, the fermented cereal-based pretzel-like product of India and Pakistan has been known since 1450 AD and is probably of Arabic or Persian origin (Gode 1943).

Soybean was probably introduced to India from China through the Himalayas several centuries ago and some believe that soybeans were also brought via Myanmar by traders from Indonesia (Shurtleff and Aoyagi 2010). *Kinema*, a fermented sticky soybean food of India, Nepal and Bhutan might have originated in east Nepal around 600 BC to 100 AD during the Kirat dynasty (Tamang 2010a). The word *kinema* was derived from the word *kinamba* of the Limboo language of the Kirat race, *ki* means fermented and *namba* means flavor (Tamang 2001). A hypothetical triangle "*natto*-triangle" was initially proposed by Nakao (1972) and was based on the distribution of plasmids (Hara et al. 1986, 1995) and the 16s RNA sequencing (Tamang et al. 2002) of the *Bacillus* species from common nonsalted sticky fermented soybean foods of Asia. An imaginary triangle known as "*Kinema-Natto-Thua nao* triangle" (KNT-triangle) was proposed by Tamang (2010a). Within the KNT-triangle in Asia only *Bacillus*-fermented soybean foods are prepared and consumed starting from Japan (*natto*), touching the Korean peninsula (*chungkokjang*), South China (*douchi*), North Thailand (*thua-nao*), Myanmar (*pepok*), Cambodia and Laos (*sieng*), southern Bhutan, the Darjeeling hills and Sikkim in India, and eastern Nepal (*kinema*), and the North East Indian states of Meghalaya (*tungrymbai*), Manipur (*hawaijar*), Mizoram (*bekang*), Nagaland (*aakhone*), and Arunachal Pradesh (*peruyaan*). The proposed "KNT triangle" does not include nonsticky and nonbacilli fermented soybean products such as *tempeh, miso, sufu, shoyu*, and so on.

Asian fermented soybean foods might have originated from *douchi* or *tau-shi*, during the Han dynasty in southern China around 206 BC (Bo 1984a,b, Zhang and Liu 2000). *Natto*, a fermented sticky soybean, was introduced to Japan from China by Buddhist priests during the Nara period around 710–794 AD (Itoh et al. 1996, Kiuchi 2001). Production of *shoyu* and *miso* in China was recorded around 1000 BC with the transfer of knowledge of production of *shoyu* and *miso* to Japan in around 600 AD (Yokotsuka 1985). *Tempeh*, the mold-fermented soybean food of Indonesia was originally introduced by ethnic Chinese traders in the early seventeenth century and the earliest record of the word tempeh appeared in the Serat Centini manuscript around 1815 AD (Astuli 1999).

The oldest sacred books of the Hindus, the *Rig Veda* and the *Upanishads* mentioned the origin of *dahi*, one of the oldest yoghurt-like fermented milk products of India during 6000–4000 BC (Yegna Narayan Aiyar 1953). Some milk products of Sudan and Egypt consumed in modern Africa such as *rob* (made from cow/goat/sheep milk), *gariss* (from camel milk), *biruni* (cow/camel milk) of Sudan, and *mish* (cow/camel milk) were mentioned by medieval Arab travelers (Odunfa 1988, Dirar 1993). The ancient Turkish people in Asia who lived as nomads were the first to make yoghurt, called "yoghurut" (Rasic and Kurmann 1978). The Babylonian records refer to cheese in 2000 BC (Davis 1964). The importance of cheese in the food habits of people in Greece (1500 BC) and Rome (750 BC) has been well documented (Scott 1986).

The Mekong basin of south-west China, Laos and northern and north-west Thailand were the most probable place of origin of fermented fish products in Asia (Ishige 1993, Ruddle 1993). Consumption of sausage by the ancient Babylonians was recorded around 1500 BC (Pederson 1979). The name *salami* is believed to have originated from the city of Salamis located on the east cost of Cyprus, which was destroyed in 449 BC (Lücke 1985).

1.1.2 History of Alcoholic Drinks

Fermented beverages appeared in 5000 BC in Babylon, 3150 BC in Ancient Egypt, 2000 BC in Mexico and 1500 BC in Sudan (www.eolss.net/sample-chapters/c06/e6-34-09-09.pdf). The earliest evidence of the grape in Egypt is seeds in jars imported from the Levant, dating to about 3150 BC indicating that wine was possibly produced in Egypt itself by 3000 BC (Murray 2000). Archaeological findings and chemical analyses of residues recovered from the Neolithic (6th millennium BC) Hajji Firuz Tepe, and the Early Bronze Age (4th millennium BC) Godin Tepe, both in western Iran, is commonly reported to represent the earliest evidence of wine making (Renfrew 1999, Wilson 1999).

Early Mesopotamian beer was based on barley malt, that is, sprouted and dried grain (Curtis 2001). Analysis of ancient beer residues using scanning electron microscopy was more focused on archaeological evidence (Samuel 1996, 2000). The whole starch remaining in the unheated malt would have broken down more slowly and the source of fermentation is uncertain (Samuel 2000). Archaeobotanical evidence from northern Germany and Scandinavia shows that hops and sweet gale (*Myrica gale*) became important beer flavorings in early medieval times (ninth to tenth century AD) (Behre 1984).

Pulque, one of the ancient alcoholic beverages of South America, which is fermented from *agave* juice and now is the national drink of Mexico was inherited from the Aztecs (Goncalves de Lima 1975). Another ancient alcoholic drink of the Andes Indians living in the lower altitude regions of South America is *chicha*, prepared from maize through human saliva which serves as the source of amylase for conversion of starch into fermentation sugars (Escobar 1977).

During the *Vedic* period of Indian history (2500–200 BC), based originally around the Indus River system, alcoholic drink *soma rus* was common and was worshipped as the liquid god *Soma* because of its medicinal attributes (Bose 1922, Sarma 1939). Drinking of alcohol in India has been mentioned in the *Ramayana* during 300–75 BC (Prakash 1961). The malting process as well as wine fermentation is rarely used in traditional fermentation processes in Asia, instead, amylolytic mixed starters prepared from the growth of molds and yeasts on raw or cooked cereals are more commonly used (Tamang 2010c). The use of traditionally prepared amylolytic mixed starters, common to the Himalayas and South East Asia, might have its origins during the time of Euchok, the daughter of the legendary king of Woo of China, known as the goddess of rice-wine in Chinese culture in 4000 BC (Lee 1984). The first documentation of *chu*, the mixed amylolytic starter of China (use for production of fermented beverages and alcoholic drinks), was found in the Shu-Ching document written during the Chou dynasty (1121–256 BC) (Haard et al. 1999). The use of *chu* for fermentation of rice-based alcoholic beverages and drinks was recorded in the beginning of the Three Nations' Periods in Korea during first century BC to second century AD (Lee 1995). The word *ragi*, an amylolytic starter of Indonesia, was first noted on an ancient inscription called the Kembang Arum near Yogyakarta in Java around 903 AD (Astuli 1999). *Kodo ko jaanr*, the ethnic fermented finger millet alcoholic beverage of the Himalayas was mentioned in the history of Nepal during the Kirat dynasty in 625 BC to 100 AD (Adhikari and Ghimirey 2000). The Newar community of Nepal used to ferment alcoholic beverages from rice during the Malla dynasty in 880 AD (Khatri 1987). There are brief descriptions of the fermented millet beverages of the Darjeeling hills and Sikkim in India in historical documents (Hooker 1854, Risley 1928, Gorer 1938).

1.2 Protocol for Studying Fermented Foods

Protocols for studies of ethnic fermented foods and alcoholic beverages primarily focus on the following parameters (Tamang 2014):

1. Documentation of the indigenous knowledge of the local people of traditional preparation, culinary practices, mode of consumption, ethnical values, therapeutic uses, socio-economy, market survey of marginal producers of fermented foods/alcoholic beverages using standard format; photography.
2. Sensory character(s) of a fermented food or alcoholic beverage by a researcher: taste, texture, aroma/flavor, and appearance.
3. Calculation of per capita consumption and annual production of ethnic fermented foods and alcoholic beverages of the particular region/village.
4. Determination of pH, temperature of the product *in situ*.
5. Collection of samples aseptically in pre-sterile containers.
6. Microbiology of fermented foods: determination of microbial loads of microorganisms (bacteria, yeasts, molds) and pathogenic contaminants (colony forming unit per gram or liter of sample), isolation of cultivable microorganisms.
7. Identification of isolates: phenotypic (morphological, physiological, and biochemical tests) and molecular identifications, assigning the proper identification of functional microorganisms following the standard norm of ICBN for microorganisms and well-authenticated taxonomical keys.

8. Isolation of uncultured microorganisms directly from food samples, and identification by culture-independent molecular techniques.
9. Preservation of identified strains of microorganisms in 15% glycerol at 80°C, or lyophilized, and deposited at authorized culture collection centers.
10. Experiments on fermentation dynamics or microbial changes during *in situ* fermentation to understand the role of functional or nonfunctional microorganism(s) using culture-independent techniques during natural fermentation.
11. Determination of the proximate composition and nutritional values of the products.
12. Determination of functional properties: probiotics, antioxidants, antimicrobial activities, tyrosinase inhibition, cell proliferation and MMP-2 inhibition activities, degradation of antinutritive compounds, bioactive compounds, unsaturated fatty acids, including omega 3-fatty acids, isoflavones and saponins, total phenolic compounds, total anthocyanin, saponin, and so on.
13. Studies on food safety: occurrence of pathogenic and spoilage microorganisms, toxin production, shelf-life of the products.
14. Optimization of a traditional process using a starter culture(s), consisting either of a pure culture or of a consortium of identified native microorganism(s) with desirable functional properties.
15. Organoleptic evaluation and consumer preference trials of the product prepared on laboratory scale.

1.3 Microorganisms

Microorganisms determine the characteristics of fermented food, for example, acidity, flavor and texture, as well as the health benefits that go beyond simple nutrition (Vogel et al. 2011). Microorganisms may be present as the indigenous microbiota of the food or as a result of the intentional addition of microorganisms as starter cultures in an industrial food fermentation process (Stevens and Nabors 2009). Also, microbial cultures can be used to produce several compounds (enzymes, flavors, fragrances, etc.) either specifically for application as food additives or *in situ* as a part of food fermentation processes (Longo and Sanromán 2006).

With an estimated 5000 varieties of fermented foods and beverages, worldwide, only a small fraction of these artisanal products have been subjected to scientific studies so far (Tamang 2010b). In many of these foods, the biological and microbiological bases of the fermentation processes are poorly understood. What little information is available often deals with the identification and perhaps preliminary characterization of the primary microbiota in the finished product. This in turn will necessitate a more thorough understanding of the microorganisms involved, in terms of the types and their specific activities, so that the fermentation process can be made more reliable and predictable.

With the discovery of microorganisms, it became possible to understand and manage food fermentation. Methods for isolating and purifying microbial cultures became available in the nineteenth century. Sterilization or pasteurization of the raw materials prior to inoculation with well-defined cultures allowed the fermentation processes to be managed with little variation. The use of defined cultures became the industrial standard in breweries by the nineteenth century. During the twentieth century, the wine, dairy, and meat industries also shifted production procedures toward the use of well-characterized and defined starter cultures. In the beginning, starter cultures were isolates from earlier fermentations that were maintained and propagated at the site of production. The application of microbiology and process technology resulted in large improvements in the quality of the fermented food products. The quality improvements have been so great that today all significant production of fermented food is industrial. The small amount of "home fermentation" conducted in the form of baking, home brewing and private cheese making usually rely on commercially available yeast and bacterial cultures. The maintenance of the microorganisms differs between the different food industries in the sense that some fermentation industries, such as breweries and vinegar producers maintain their own stains and inocula. In the dairy industry, as well as in the meat industry and bakeries, cultures are usually obtained from suppliers dedicated to the production of high-quality food ingredients (Mogensen et al. 2002, Hansen 2004).

Fermentation can basically be performed either by natural or spontaneous fermentation, by back-slopping or by the addition of starter cultures. By spontaneous fermentation, the raw material and its initial treatment will encourage the growth of an indigenous microbiota. In most spontaneous fermentation, a microbial succession takes place: quite often lactic acid bacteria (LAB) will initially dominate followed by various species of yeasts. Molds only grow aerobically, limiting their occurrence in certain types of fermented products. LAB produce lactic acid and other antimicrobial substances that inhibit the growth of harmful bacteria along with reducing the sugar content, thereby prolonging the shelf life of the product. Yeasts mostly produce aroma components and alcohols. When molds are involved in fermentation, they generally contribute by producing both intra- and extracellular proteolytic and lipolytic enzymes that highly influence the flavor and texture of the product (Tamang and Fleet 2009).

In back-slopping, a part of a precious batch of a fermented product is used to inoculate the new batch. This procedure produces a higher initial number of beneficial microorganisms than that found in the raw material and ensures a faster and more reliable fermentation than that which occurs in spontaneous fermentation. Examples of back-slopping are home-made fermentation of milk, vegetables, and cereals (Josephsen and Jespersen 2004).

Novel insights into the metabolism of LAB offer perspectives for the application of a new generation of starter cultures. Functional starter cultures are starters that possess at least one inherent functional property. These can contribute to food safety and/or offer one or more organoleptic, technological, nutritional, or health advantage. The implementation of carefully selected strains as starter cultures or co-cultures in fermentation processes can help to achieve *in situ* expression of the desired property, maintaining a perfectly natural and healthy product. A functional LAB starter culture is able to produce antimicrobial substances, sugar polymers, sweeteners, aromatic compounds, useful enzymes, or nutraceuticals, while-the so-called probiotic strains, mainly LAB, exhibit health-promoting properties. Such functionalities also lead to a wider application area and higher flexibility of starter cultures (Leroy and De Vuyst 2004). Nowadays, there are many commercial suppliers of starter cultures worldwide, such as Alce and CSL (Italy), ASCRS (Australia), Chr. Hansen and Danisco (Denmark), CSK and DSM (the Netherlands), Degussa and Gewürzmüller (Germany), Lallemand (Canada), NZDRI (New Zealand), Quest International (UK), Rhodia (France), and so on. All companies can easily be found on the Internet/World wide Web (Hansen 2002, 2004).

Fermented foods are the hubs of consortia of microbiota and mycobiota (functional, nonfunctional, and pathogenic contaminants), which may be present as natural indigenous microbiota in uncooked plant or animal substrates, utensils, containers, earthen pots, or environments (Hesseltine 1983, Tamang 1998), or as a result of the intentional addition of the microorganisms as starter cultures in an industrial food fermentation process (Stevens and Nabors 2009). Functional microorganisms transform the chemical constituents of raw materials of plant/animal sources during fermentation thereby enhancing the nutritional value of the products, enriching them with improved flavor and texture, prolonging their shelf live, and fortifying them with health-promoting bio-active compounds (Farhad et al. 2010). Species of lactic acid bacteria and *Bacillus*, and amylolytic and alcohol-producing yeasts and filamentous molds are the major microbiota in the fermented foods and alcoholic beverages of Asia, whereas LAB or a combination of bacteria (LAB, non-LAB, micrococci)-yeast mixtures and filamentous molds are more prominent in Africa. Filamentous molds and bacilli are rare in the fermented foods and beverages of Africa, Europe, Australia, and America (Tamang 1998), although fermented legume products, based on *Bacillus* fermentation, are common in West Africa (Oguntoyinbo et al. 2007).

1.3.1 Isolation by Culture-Dependent and Culture-Independent Methods

The classical phenotypic identification methods are totally based on culture-dependent techniques for only cultivable microorganisms in culture media, ignoring several unknown uncultivable microorganisms that may have major or minor functional roles in the production of fermented foods. Direct DNA extraction from samples of fermented foods commonly referred to as culture-independent methods are nowadays commonly used in food microbiology to profile both cultivable and uncultivable microbial populations from fermented foods (Cocolin and Ercolini 2008). Culture independent techniques first appeared in food microbiology at the end of the 1990s and since then they have been applied extensively. These methods do not rely on cultivation and target nucleic acids (DNA and RNA) to identify and follow the changes that occur in the main populations present in a specific ecosystem (Cocolin et al. 2013). The most popular culture-independent technique being used in the isolation of microorganisms from fermented foods is a PCR-DGGE analysis to profile bacterial populations (Cocolin et al. 2011, Tamang 2014) and yeast populations in fermented foods (Cocolin et al. 2002, Jianzhonga et al. 2009). Culture-dependent and culture-independent methods are contradictory to each other (Alegría et al. 2011), but for microbial taxonomy both methods are equally important and complementary. Both cultivable and uncultivable microorganisms from any fermented food and beverage may be identified using culture-dependent and -independent methods to document a complete profile of native functional and nonfunctional microorganisms, and to study both inter- and intra-species diversity within a particular genus or among genera (Ramos et al. 2010, Yan et al. 2013, Tamang 2014). Greppi et al. (2013a) first reported the combination of both culture-dependent and independent methods to reveal predominant yeast species and biotypes in the traditional fermented maize foods of Benin. The DGGE analysis on the DNA directly extracted from fermented maize products demonstrated the presence of *Dekkera bruxellensis* and *Debaryomyces hansenii*, not detected by the culture-based approach (Greppi et al. 2013b).

1.3.2 Identification: Phenotypic and Biochemical

Phenotypic characteristics include colony appearance, cell morphology, Gram staining, growth at different temperatures (8–65°C), pH (3.9–9.6), and salt tolerance (4.0%–18%). Biochemical tests are based on the metabolic activities of microorganisms such as carbon and nitrogen sources, energy sources, sugar fermentation, secondary metabolite formation, and enzyme production (Tamang 2014). A few ready-to-use commercial identification kits are commonly used such as API 50CH (bioMérieux, France) for rapid sugar fermentation tests, and the Biolog Microbial Identification System, for identification of different groups of bacteria and yeasts.

1.3.3 Identification: Genotypic or Molecular

Molecular identification is emerging as an accurate and reliable identification tool, and is widely used in identification of both culture-dependent and culture-independent microorganisms from fermented foods. Owing to a variety of tools that provide advanced molecular differentiation of microorganisms, microbial populations can be quantified and new microbial species isolated and identified (Giraffa and Carminati 2008). Some common molecular tools used in identification of microorganisms isolated from fermented foods are species-specific PCR, qPCR, rep-PCR, AFLP, RAPD, DGGE, TGGE, ARDRA, mtDNA-RFLP, mCOLD-PCR, MLSA, and MLST.

Species-specific PCR primers are used to identify a particular species of the genus (Tamang et al. 2005); this technique is widely applied in the identification of LAB isolated from fermented foods (Robert et al. 2009). The application of real-time quantitative PCR (qPCR) with specific primers provides the specific detection and quantification of LAB species in fermented foods (Park et al. 2009). The repetitive extragenic palindromic sequence-based PCR (rep-PCR) technique permits typing at a subspecies level and reveals significant genotypic differences between strains of the same bacterial species from fermented foods (Tamang et al. 2008). Amplified fragment-length polymorphism (AFLP) is a technique based on the selective amplification and separation of genomic restriction fragments, and its applicability is for the identification of various LAB strains in fermented foods (Tanigawa and Watanabe 2011). Random amplification of polymorphic DNA (RAPD) is commonly used for discrimination of LAB strains from fermented foods (Schillinger et al. 2003, Chao et al. 2008). The amplified ribosomal DNA restriction analysis (ARDRA) technique using restriction enzymes is also useful in identification of uncultivable microorganisms from fermented foods (Jeyaram et al. 2010). The mt DNA-RFLP technique showed discriminating power similar to microsatellite typing and interdelta analysis (Schuller et al. 2007) and is considered as a useful genetic marker for *Saccharomyces cerevisiae* in amylolytic starters (Jeyaram et al. 2011). Techniques of denaturing gradient gel electrophoresis (DGGE) and temperature gradient gel electrophoresis (TGGE) have been developed to profile microbial communities directly from fermented foods, and are based on sequence-specific distinctions of 16S rDNA or 26S rDNA amplicons produced by PCR (Ongol and Asano 2009, Alegría et al. 2011). A modified CO-amplification at lower denaturation temperature PCR (mCOLD-PCR) method has been developed to detect low-abundant microorganisms using a double-strand RNA probe to inhibit the amplification of the sequence of a major microorganism in wine fermentation (Takahashi et al. 2014). Multilocus sequence analysis (MLSA) using housekeeping genes as molecular markers alternative to the 16S rRNA genes, has been proposed for LAB species identification from fermented foods (Naser et al. 2005, de Bruyne et al. 2007, 2008, 2010). Multilocus sequence typing (MLST) has also been used for discriminating LAB strains from fermented foods (Diancourt et al. 2007, Picozzi et al. 2010, Tanigawa and Watanabe 2011).

Effective tools of next-generation sequencing (NGS) such as phylobiomics, metagenomics, and metatranscriptomics are required for the documentation of cultures in traditional fermented products, for sensory quality and safety improvements, in some cases for starter culture design for commercialization and potentially for supporting sustainable food systems (van Hijum et al. 2013). A proteomics identification method using matrix-assisted laser desorption ionizing-time of flight mass spectrometry (MALDI-TOF MS) is used to identify the species of *Bacillus* in the fermented foods of Africa (Savadogo et al. 2011), *Lactobacillus* strains isolated from fermented foods (Dušková et al. 2012, Sato et al. 2012), sub-speciation of *Lactococcus* (*Lc.*) *lactis* (Tanigawa et al. 2010), LAB from traditional fermented vegetables of Vietnam (Nguyen et al. 2013b), probiotics from yoghurt (Angelakis et al. 2011), and *Tetragenococcus halophilus* and *Tetra. muriaticus* from fermented foods

(Kuda et al. 2014). The application of NGS such as metagenomic approaches using massively parallel pyrosequencing of tagged 16S rRNA gene amplicons provide detailed information on microbial communities associated with *kimchi* (Jung et al. 2011, Park et al. 2012), *nukadoko*, a fermented rice bran mash used for pickling vegetables in Japan (Sakamoto et al. 2011), *narezushi*, a fermented salted fish with cooked rice in Japan (Kiyohara et al. 2012), and *ben-saalga*, a traditional gruel of pearl millet in Burkina Faso (Humblot and Guyot 2009). The 16S rRNA gene sequence-based pyrosequencing method enables a detailed, comprehensive and high-throughput analysis of microbial ecology (Sakamoto et al. 2011), and this method has been applied to various traditional fermented foods (Oki et al. 2014). Compared to the pyrosequencing analysis, the DGGE method only revealed some of the major bacterial species such as *Bacillus thermoamylovorans* and *B. licheniformis* in *chungkokjang* (the sticky fermented soybean food of Korea) and could not detect a large number of predominant or diverse rare bacterial species identified in the pyrosequencing analysis. Also the regional differences of the bacterial community were more clearly represented in the pyrosequencing method than in the DGGE analysis (Nam et al. 2011).

Metabolomics, also called metabonomics or metabolic profiling, deals with the simultaneous determination and quantitative analysis of intracellular metabolites or low-molecular-mass molecules and can be used as a tool for the comprehensive understanding of fermented and functional foods with LAB (Mozzi et al. 2013). The application of species-independent functional gene microarray for identification of LAB in fermented foods has been developed (Weckx et al. 2009). Up-to-date analytical methods have also been applied in the identification and discrimination of some microbial species/strains from fermented foods such as length heterogeneity PCR (LH-PCR), high-throughput sequencing (HTS), BOX-PCR (Zhu et al. 2014), and so on.

1.4 Main Types of Microorganisms in Global Food Fermentation

Main types (with genera) of microorganisms associated with global fermented foods and beverages are grouped as follows (Bernardeau et al. 2006, Tamang and Fleet 2009, Tamang 2010a,b,c, Bourdichon et al. 2012, Alexandraki et al. 2013):

- Bacteria: *Acetobacter, Arthrobacter, Bacillus, Bifidobacterium, Brachybacterium, Brevibacterium, Carnobacterium, Corynebacterium, Enterobacter, Enterococcus, Gluconacetobacter, Hafnia, Halomonas, Klebsiella, Kocuria, Lactobacillus, Lactococcus, Leuconostoc, Macrococcus, Microbacterium, Micrococcus, Oenococcus, Pediococcus, Propionibacterium, Staphylococcus, Streptococcus, Streptomyces, Tetragenococcus, Weisella, Zymomonas.*
- Fungi: *Actinomucor, Aspergillus, Fusarium, Lecanicillium, Mucor, Neurospora, Penicillium, Rhizopus, Scopulariopsis, Sperendonema.*
- Yeasts: *Candida, Cyberlindnera, Cystofilobasidium, Debaryomyces, Dekkera, Hanseniaspora, Kazachstania, Galactomyces, Geotrichum, Guehomuces, Kluyveromyces, Lachancea, Metschnikowia, Pichia, Saccharomyces, Schizosaccharomyces, Schwanniomyces, Starmerella, Torulaspora, Trigonopsis, Wickerhamomyces, Yarrowia, Zygosaccharomyces, Zygotorulaspora.*

1.4.1 Bacteria

Bacteria are the most dominant microorganisms in both naturally fermented foods or foods fermented by the use of starter cultures. Among the bacteria, lactic acid bacteria are commonly associated with acidic fermented foods, while non-LAB bacteria such as *Bacillus*, micrococcaceae, *Bifidobacterium*, *Brachybacterium*, *Brevibacterium*, and *Propionibacterium* etc., are also involved in food fermentation, frequently as minor or secondary groups.

1.4.1.1 Lactic Acid Bacteria

Lactic acid bacteria are Gram-positive, catalase-negative bacteria that produce large amounts of lactic acid. The bacterial groups that make up the LAB are among the most familiar to humans, because of their association with the human environment, and with a wide range of naturally fermented dairy products, grain crops, vegetables, and so on. The LAB comprise a large bacterial group consisting of about 380 species in 40 genera of 6 families, belonging phylogenetically to the order *Lactobacillales* within the phylum *Firmicutes* (Stiles and Holzapfel 1997). Common genera of the LAB isolated from various fermented foods of the world are *Alkalibacterium*, *Carnobacterium*, *Enterococcus*, *Lactococcus*, *Lactobacillus*, *Leuconostoc*, *Oenococcus*, *Pediococcus*, *Streptococcus*, *Tetragenococcus*, *Vagococcus*, and *Weissella* (Carr et al. 2002, Salminen et al. 2004, MetaMicrobe.com/Lactic Acid Bacteria 2013).

1.4.1.2 Non-Lactic Acid Bacteria

Bacillus is reported from the alkaline-fermented foods of Asia and Africa (Parkouda et al. 2009). Species of *Bacillus* present in fermented foods mostly soybean-based foods are *B. amyloliquefaciens*, *B. circulans*, *B. coagulans*, *B. firmus*, *B. licheniformis*, *B. megaterium*, *B. pumilus*, *B. subtilis*, *B. subtilis* variety *natto* and *B. thuringiensis* (Kiers et al. 2000, Kubo et al. 2011), while strains of *B. cereus* have been isolated from the fermentation of *Prosopis africana* seeds for the production of *okpehe* in Nigeria (Oguntoyinbo et al. 2007). Some strains of *B. subtilis* produce λ-polyglutamic acid (PGA) which is an amino acid polymer commonly present in Asian fermented soybean foods giving the characteristic sticky texture to the product (Urushibata et al. 2002, Meerak et al. 2007, Nishito et al. 2010).

Species of *Bifidobacterium*, *Brachybacterium*, *Brevibacterium*, and *Propionibacterium* have been isolated from cheese and other fermented milks (Bourdichon et al. 2012). Several species of *Kocuria*, *Micrococcus*, and *Staphylococcus* have been reported from fermented milk products, fermented sausages and meat and fish products (Wu et al. 2000, Martín et al. 2006, Coton et al. 2010). *Enterobacter cloacae*, *Klebsiella pneumoniae*, *K. pneumoniae* subsp. *ozaenae*, *Haloanaerobium*, *Halobacterium*, *Halococcus*, *Propionibacterium*, *Pseudomonas*, and so on, are also present in many fermented foods (Tamang 2010b). Species of *Arthrobacter* and *Hafnia* are involved in meat fermentation (Bourdichon et al. 2012).

1.4.2 Yeasts

The role of yeasts in food fermentation is to ferment sugar, produce secondary metabolites, inhibit growth of mycotoxin-producing molds and display several enzymatic activities such as lipolytic, proteolytic, pectinolytic, glycosidasic and urease activities (Aidoo et al. 2006, Romano et al. 2006). Genera of yeasts reported from fermented foods, alcoholic beverages and nonfood mixed amylolytic starters are *Brettanomyces*, *Candida*, *Cryptococcus*, *Debaryomyces*, *Dekkera*, *Galactomyces*, *Geotrichum*, *Hansenula*, *Hanseniaspora*, *Hyphopichia*, *Issatchenkia*, *Kazachstania*, *Kluyveromyces*, *Metschnikowia*, *Pichia*, *Rhodotorula*, *Rhodosporidium*, *Saccharomyces*, *Saccharomycodes, Saccharomycopsis, Schizosaccharomyces, Sporobolomyces, Torulaspora, Torulopsis, Trichosporon, Yarrowia*, and *Zygosaccharomyces* (Watanabe et al. 2008, Tamang and Fleet 2009, Kurtzman et al. 2011, Lv et al. 2013).

1.4.3 Fungi

The major roles of fungi, mostly filamentous molds, in fermented foods and alcoholic beverages are the production of intra- and extracellular proteolytic and lipolytic enzymes that highly influence the flavor and texture of the product, and also the degradation of antinutritive factors improving bioavailability of minerals (Josephsen and Jespersen 2004, Aidoo and Nout 2010). Species of *Actinomucor, Amylomyces, Aspergillus, Monascus, Mucor, Neurospora, Penicillium, Rhizopus*, and *Ustilago* are reported from many fermented foods, Asian nonfood amylolytic starters and alcoholic beverages (Hesseltine 1991, Nout and Aidoo 2002).

1.4.4 Pathogenic Contaminants

About 80% of fermented foods are produced by natural fermentation and may contain functional, nonfunctional, and pathogenic microorganisms during initial fermentation. Pathogenic bacteria commonly reported for fermented foods are *Escherichia coli, Listeria monocytogenes, Yersinia enterocolitica, Bacillus cereus, Clostridium botulinum*, and so on (Lindqvist and Lindblad 2009, Rossi et al. 2011).

1.4.5 Gut Microflora

The human gastrointestinal tract (GIT) houses over 10^{14} microbial cells with over 1000 diverse bacterial types, mostly in the colon (Lepage et al. 2012, Purchiaroni et al. 2013). Colonization of the gut is initiated before birth following ingestion of microbe-containing amniotic fluid by the fetus (Mshvildadze and Neu 2010, Aagaard et al. 2014). The majority of bacteria in the adult gut are nonsporing anaerobes, the most numerically predominant of which include species of *Bacteroides, Bifidobacterium, Eubacterium, Clostridium, Lactobacillus, Fusobacterium*, and various Gram-positive cocci and bacteria that are present in lower numbers include *Enterococcus* spp., Enterobacteriaceae, methanogens, and dissimilatory sulfate-reducing bacteria (Wallace et al. 2011). Microorganisms colonize different parts of GIT and bacterial population density varies along the GIT (Romano-Keeler et al. 2014). The GIT is one of the most complex ecosystems of microorganisms ranging from bacteria (mostly LAB), archaea (e.g., methanogens), and eukarea (fungi, helminthes, and protozoa) as well as viruses (Mitsuoka 1992, Holzapfel et al. 1997, Norman et al. 2014). In healthy adults, 80% of the identified fecal microbiota belong to four dominant phyla: the Gram-negative *Bacteroides* and *Proteobacteria* and the Gram-positive *Actinobacteria* and *Firmicutes* which include at least 17 families, corresponding to no less than 1250 different species of bacteria (Schuijt et al. 2013). The composition and distribution of gut microbiota (Purchiaroni et al. 2013) are as follows: in the stomach (*Lb. reuteri, Lb. delbrueckii, Lb. gastricus, Lb. antri*), in the small intestine (*Lb. reuteri, Lb. bulgaricus, Lb. acidophilus, Enterococcus avium, Ent. dispar, Ent. durans, Ent. faecalis, Ent. faecium, Ent. flavescens, Ent. gallinarum, Ent. hirae, Ent. mundtii, Ent. raffinosus*), and in the large intestine (*Ent. faecalis, Bacteroides, Bifidobacterium, Eubacterium, Peptococcurs, Clostridium, Lactobacillus*).

1.5 Types of Fermented Foods

The major groups of substrates-based fermented foods are as follows:

1. Fermented milk foods
2. Fermented cereal foods
3. Fermented vegetable foods
4. Fermented soybean and non-soybean foods
5. Fermented meat products
6. Fermented fish products
7. Fermented root/tuber products
8. Fermented beverages and Asian amylolytic starters
9. Miscellaneous fermented products (fermented tea, cocoa, vinegar, *nata, pidan*, etc.)

1.5.1 Fermented Milks

Fermented milks (Table 1.1) are classified into two major groups based on the presence of dominant microorganisms: (i) lactic fermentations which are dominated by species of LAB, and consist of the thermophilic type (e.g., yogurt, Bulgarian buttermilk), probiotic type (acidophilus milk, yakult, bifidus milk), and the mesophilic type (e.g., natural fermented milk, cultured milk, cultured cream, cultured buttermilk); and (ii) fungal-lactic fermentations where LAB and yeasts species cooperate to generate the final product and consist of alcoholic milks (e.g., *kefir, koumiss*, acidophilus-yeast milk), and moldy milks (e.g., *viili*) (Mayo et al. 2010). Starter cultures in milk fermentation are of two types depending on the principal function, primary cultures to participate in the acidification, and secondary cultures for flavor, aroma, and maturing activities (Topisirovic et al. 2006). The main species involved as primary cultures in milk fermentation are *Lactococcus lactis* subsp. *cremoris, Lc. lactis* subsp. *lactis, Lactobacillus delbrueckii* subsp. *delbrueckii, Lb. delbrueckii* subsp. *lactis, Lb. helveticus, Leuconostoc* spp., and *Streptococcus thermophilus* (Parente and Cogan 2004). Secondary cultures used in cheese making are *Brevibacterium linens, Propionibacterium freudenreichii, Debaryomyces hansenii, Geotrichum candidum, Penicillium camemberti*, and *P. roqueforti* for the development of flavor and texture during the ripening of cheese (Coppola et al. 2006, Quigley et al. 2011). Besides primary and secondary cultures, some nonstarter lactic acid bacteria (NSLAB) microbiota are usually present in high numbers which include *Enterococcus durans, Ent. faecium, Lb. casei, Lb. plantarum, Lb. salivarius*, and *Staphylococcus* spp. (Briggiler-Marcó et al. 2007). Yogurt is a widely consumed highly nutritious fermented milk as a coagulated milk product resulting from the fermentation of milk by *Strep. thermophilus* and *Lb. delbrueckii* subsp. *bulgaricus* (formerly *Lb. bulgaricus*) (Tamime and Robinson 2007). *Lb. acidophilus, Lb. casei, Lb. rhamnosus, Lb. gasseri, Lb. johnsonii*, and *Bifidobacterium* spp., are among the most common adjunct cultures in yogurt fermentation (Guarner et al. 2005). Fermented milk products that are manufactured using starter cultures containing yeasts include acidophilus-yeast milk, *kefir, koumiss*, and *viili* (de Ramesh et al. 2006). *Lb. acidophilus, Lb. amylovorus, Lb. crispatus, Lb. gallinarum, Lb. gasseri*, and *Lb. johnsonii* are reported from acidophilus milk (Berger et al. 2007).

Natural fermented milks are one of the oldest methods of milk fermentation using raw or boiled milk to ferment spontaneously or by using the back-slopping method (Robinson and Tamime 2006). In back-slopping, a part of a precious batch of a fermented product is used to inoculate the new batch

Table 1.1 Some Common and Uncommon Ethnic Fermented Milk Products of the World

Product	*Substrate*	*Sensory Property and Nature*	*Microorganisms*	*Country*	*References*
Acidophilus milk	Cow milk	Acidic, sour, drink	Species of *Lactobacillus*, *Lactococcus*	Russia, East Europe, Greece, Turkey, North America, Scandinavia	Mayo et al. (2010)
Airag	Mare or camel milk	Acidic, sour, mild alcoholic, drink	*Lb. helveticus*, *Lb. kefiranofaciens*, *Bifidobacterium mongoliense*, *Kluyveromyces marxianus*	Mongolia	Watanabe et al. (2008, 2009b)
Ayib	Goat milk		*Canida* sp., *Saccharomyces* sp., *Lactobacillus* sp., *Leuconostoc* sp.	East and Central Africa	Odunfa and Oyewole (1997)
Biruni	Cow/camel milk	Acidic, semi-liquid, drink	LAB	Sudan	Jung (2012)
Butter	Animal milk	Soft paste, butter	LAB	Worldwide	Mayo et al. (2010)
Buttermilk		Acid fermented butter milk	*Lb. bulgaricus*	Bulgaria	Mayo et al. (2010)
Cheese	Animal milk	Soft or hard, solid; side dish, salad	*Lc. lactis* subsp. *cremoris*, *Lc. lactis* subsp. *lactis*, *Lb. delbrueckii* subsp. *delbrueckii*, *Lb. delbrueckii* subsp. *lactis*, *Lb. helveticus*, *Lb. casei*, *Lb. plantarum*, *Lb. salivarius*, *Leuconostoc* spp., *Strep. thermophilus*, *Ent. durans*, *Ent. faecium*, and *Staphylococcus* spp., *Brevibacterium linens*, *Propionibacterium freudenreichii*, *Debaryomyces hansenii*, *Geotrichum candidum*, *Penicillium camemberti*, *P. roqueforti*.	Worldwide	Parente and Cogan (2004), Quigley et al. (2011)

Chhu	Yak/cow milk	Cheese like product, curry, soup	*Lb. farciminis, Lb. brevis, Lb. alimentarius, Lb. salivarius, Lact. lactis, Saccharomycopsis* sp., *Candida* sp.	India, Nepal, Bhutan, China (Tibet)	Dewan. and Tamang (2006)
Chhurpi (hard)	Yak/cow milk	Chewable milk, masticator	*Lb. farciminis, Lb. casei, Lb. biofermentans, W. confusus*	India, Nepal, Bhutan, China (Tibet)	Tamang (2010a)
Chhurpi (soft)	Yak/cow milk	Cheese-like product, soup, curry, pickle	*Lb. farciminis, Lb. paracasei, Lb. biofermentans, Lb.plantarum, Lb. curvatus, Lb. fermentum, Lb. alimentarius, Lb. kefir, Lb. hilgardii, W. confusus, Ent. faecium, Leuc. mesenteroides*	India, Nepal, Bhutan, China (Tibet)	Tamang et al. (2000)
Dahi	Cow/buffalo milk, starter culture	Curd, savory	*Lb. bifermentans, Lb. alimentarius, Lb. paracasei, Lact. lactis, Strep. cremoris, Strep. lactis, Strep. thermophilus, Lb.bulgaricus, Lb. acidophilus, Lb. helveticus, Lb. cremoris, Ped. pentosaceous, P. acidilactici, W. cibara, W. paramesenteroides, Lb. fermentum, Lb. delbrueckii* subsp. *indicus, Saccharomycopsis* sp., *Candida* sp.	India, Nepal, Sri Lanka, Bangladesh, Pakistan	Harun-ur-Rashid et al. (2007), Patil et al. (2010)
Ergo	Milk	Acid fermented butter milk	*Lactobacillus* sp., *Lactococcus* sp.	Ethiopia	Steinkraus (1996)
Filmjölk	Cow milk	Less-sour than yoghurt, yoghurt-like	*Lc. lactis* and *Leuc. mesenteroides*	Sweden	Kosikowski and Mistry (1997)
Gariss	Camel milk	Acidic, liquid, refreshing beverage	LAB	Sudan	Akabanda et al. (2013)
Gheu/ghee	Cow milk	Soft, oily mass, solid, butter	*Lc. lactis* subsp. *lactis, Lc. lactis* subsp. *cremoris*	India, Nepal, Bhutan, Bangladesh, Pakistan	Tamang (2010a)

(Continued)

Table 1.1 (*Continued*) Some Common and Uncommon Ethnic Fermented Milk Products of the World

Product	*Substrate*	*Sensory Property and Nature*	*Microorganisms*	*Country*	*References*
Kefir	Goat, sheep, cow	Alcoholic fermented milk, effervescent milk	*Tor. holmii, Tor. delbruechii, Lb. brevis, Lb. caucasicus,Strep. thermophilus, Lb. bulgaricus, Lb. plantarum, Lb. casei, Lb. brevis*	Russia	Bernardeau et al. (2006)
Kesong Puti, Keso, Kesiyo	Carabao's (buffalo) milk or cow carabao's milk, salt, Abomasal extracts coagulant, starter	White cheese, soft cheese	*Lb. helveticus, Lact. lactis, Lb. rhamnosus, Leuc. mesenteroides, Lb. acidophilus, Lb. plantarum, Lb. brevis, Lb. curvatus*	Philippines	Kisworo (2003)
Kishk	Milk, wheat	Fermented milk wheat mix, drink	*Lb. plantarum, Lb. brevis, Lb. bulgaricus, Lb. casei, Strep. thermophilus*	Egypt	Bernardeau et al. (2006)
Kurut	Yak milk	Naturally fermented milk, drink	LAB	China	Sun et al. (2010)
Kushuk	Milk, wheat	Fermented milk wheat mix, drink	*Lb. plantarum, Lb. brevis*	Iraq	Bernardeau et al. (2006)
Koumiss	Milk	Acid fermented milk, drink	*Lb. bulgaricus, Torula* sp., *Lb. salivarius, Lb. buchneri, Lb. heveticus, Lb. plantarum, Lb. acidophilus*	Russia	Hao et al. (2010)
Laban rayeb	Milk	Acid fermented milk, yoghurt-like	*Lb. casei, Lb. plantarum, Lb. brevis, Lact. lactis, Sacch. kefir, Leuconostoc* sp.	Egypt	Bernardeau et al. (2006)

Laban zeer	Milk	Acid fermented milk	*Lb. casei, Lb. plantarum, Lb. brevis, Lc. lactis, Lc. lactis*	Egypt	Bernardeau et al. (2006)
Lassi	Cow milk	Acidic, buttermilk, refreshing beverage	*Lb. Acidophilus, Strep. thermophilus*	India, Nepal, Bhutan, Bangladesh, Pakistan	Patidar and Prajapati (1998)
Långfil	Cow milk	Elastic texture, sour, yoghurt-like	LAB	Sweden	Tamime (2005)
Leben/Lben	Cow milk	Sour milk	*Candida* sp., *Saccharomyces* sp., *Lactobacillus* sp., *Leuconostoc* sp.,	North, East Central Africa	Odunfa and Oyewole (1997)
Liban-argeel	Sheep, goat, cow, buffalo milk	Acid fermented milk	LAB	Iraq	Bernardeau et al. (2006)
Maa	Yak milk	Mild-acidic, viscous, butter	LAB, yeasts	China (Tibet), India, Bhutan	Tamang (2010a)
Maziwa lala	Milk	Yoghurt-like	*Strep. lactis, Strep. thermophilus*	Kenya	Olasupo et al. (2010)
Mohi	Cow milk	Acidic, buttermilk, refreshing beverage	*Lb. alimentarius, Lc. lactis* subsp. *lactis, Lc. lactis* subsp. *cremoris; Saccharomycopsis* spp. and *Candida* spp.	Nepal, India, Bhutan	Dewan and Tamang (2007)
Mish	Cow/camel milk	Acidic, semi-liquid, refreshing beverage	LAB	Sudan, Egypt	Bernardeau et al. (2006)
Misti dahi (mishti doi, lal dahi, payodhi)	Buffalo/cow milk	Mild-acidic, thick-gel, sweetened curd, savory	*Strep. salivarius* subsp. *thermophilus, Lb. acidophilus, Lb. delbrueckii* subsp. *bulgaricus, Lc. lactis* subsp. *lactis, Sacch. cerevisiae.*	India, Bangladesh	Ghosh and Rajorhia (1990), Gupta et al. (2000)

(Continued)

Table 1.1 (*Continued*) Some Common and Uncommon Ethnic Fermented Milk Products of the World

Product	*Substrate*	*Sensory Property and Nature*	*Microorganisms*	*Country*	*References*
Nunu	Raw cow milk	Naturally fermented milk	*Lb. fermentum, Lb. plantarum, Lb. helveticus, Leuc. mesenteroides, Ent. faecium, Ent. italicus, Weissella confuse; Candida parapsilosis, C. rugosa, C. tropicalis, Galactomyces geotrichum, Pichia kudriavzevii, Sacch. cerevisiae*	Ghana	Akabanda et al. (2013)
Paneer	Buffalo or cow milk	Whey, soft, cheese-like product, fried snacks, curry	LAB	India, Nepal, Pakistan, Bangladesh, Middle East	Tamang (2012b)
Phrung	Yak milk	Mild-acidic, hard-mass like *chhurpi*, masticator	Unknown	India, China (Tibet)	Tamang (2010a)
Philu	Cow or yak milk, bamboo vessels	Cream like product, curry	*Lb. paracasei, Lb. bifermentans, Ent. faecium*	India, Nepal, Tibet (China)	Dewan and Tamang (2007)
Pheuja or suja	Tea-yak butter, salt	Salty with buttery flavor, liquid, Refreshing tea	Unknown	India, China (Tibet), Bhutan, Nepal	Tamang (2010a)
Rob	Cow, goat, sheep milk	Mild-acidic, savory	LAB	Sudan	Akabanda et al. (2013)
Shrikhand	Cow, buffalo milk	Acidic, concentrated sweetened viscous, savory	*Lc. lactis* subsp. *lactis, Lc. lactis* subsp. *diacetylactis, Lc. lactis* subsp. *cremoris, Strep. thermophilus, Lb. delbruecki* subsp. *Bulgaricus*	India	Aneja et al. (2002)

Somar	Yak or cow milk	Buttermilk	*Lb. paracasei, Lact. Lactis*	India, Nepal	Dewan and Tamang. (2007)
Sour milk kerbah	Milk	Acid fermented milk	*Lact. lactis, Sacch. kefir, Lb. casei, Lb. brevis, Lb. plantarum*	Egypt	Mayo et al. (2010)
Sua chua	Dried skim milk, starter, sugar	Acid fermented milk	*Lb. bulgaricus, Strep. thermophilus*	Vietnam	Alexandraki et al. (2013)
Shyow	Yak milk	Acidic, thick-gel viscous, curd-like, savory	LAB, yeasts	China (Tibet), Bhutan, India	Tamang (2010a)
Tarag	Cow, yak, goat milk	Acidic, sour, drink	*Lb. delbrueckii* subsp. *bulgaricus, Lb. helveticus, Strep. thermophilus, Sacch. cerevisiae, Issatchenkia orientalis, Kazachstania unispora*	Mongolia	Watanabe et al. (2008)
Viili	Cow milk	Thick and sticky, sweet taste, breakfast	*Lc. lactis* subsp. *lactis, Lc. lactis* subsp. *cremoris, Lc. lactis* subsp. *lactis* biovar. *Diacetylactis, Leuc. mesenteroides* subps. *cremoris, G. candidum, K. marxianus, P. fermentans*	Finland	Kahala et al. (2008)
Wara	Milk	Sweet taste, beverage	*Lc. lactis, Lactobacillus* sp.	West Africa	Olasupo et al. (2010)
Yoghurt	Animal milk	Acidic, thick-gel viscous, curd-like product, savory	*Strep. thermophilus, Lb. delbrueckii* subsp. *bulgaricus, Lb. acidophilus, Lb. casei, Lb. rhamnosus, Lb. gasseri, Lb. johnsonii, Bifidobacterium* spp.	Europe, Australia, America	Tamime and Robinson (2007)

(Josephsen and Jespersen 2004). Examples of naturally fermented milks are *dahi, lassi, misti dahi, srikhand, chhu, chhurpi, mohi, philu, shoyu, somar* (cow/buffalo/yak milk) of India, Nepal, Pakistan, Bhutan, and Bangladesh (Harun-ur-Rashid et al. 2007, Sarkar 2008, Patil et al. 2010, Tamang 2010a, Tamang et al. 2012), *kurut* of China (Sun et al. 2010), *aaruul, airag, byasulag, chigee, eezgii, tarag,* and *khoormog* of Mongolia (Watanabe et al. 2008, Takeda et al. 2011, Oki et al. 2014), *ergo* of Ethiopia, *kad, lben, laban, rayeb, zabady, zeer* of Morocco and Northern African and Middle East countries, *rob* (from camel milk), *biruni* (cow/camel milk), *mish* (cow/camel milk) of Sudan, *amasi* (*hodzeko, mukaka wakakora*) of Zimbabwe, *nunu* (from raw cow milk) of Ghana (Akabanda et al. 2013), *filmjölk* and *långfil* of Sweden (Mayo et al. 2010), *koumiss* or *kumis* or *kumys* or *kymys* of the Caucasian area (Wu et al. 2009).

Lc. lactis subsp. *cremoris*, and *Lc. lactis* subsp. *lactis* are found among the dominant microbiota along with other mesophilic lactobacilli (*Lb. casei/Lb. paracasei, Lb. fermentum, Lb. helveticus, Lb. plantarum,* and/or *Lb. acidophilus*), *Ent. faecium*, and species of *Leuconostoc* and *Pediococcus* in naturally fermented milks (Tamang et al. 2000, Mathara et al. 2004, Patrignani et al. 2006, Dewan and Tamang 2006, 2007, Yu et al. 2011, Akabanda et al. 2013). Yeasts present in naturally fermented milks are *Candida lusitaniae, C. parapsilosis, C. rugosa, C. tropicalis, Kluyveromyces* (*Kl.*) *marxianus, Sacch. cerevisiae, Galactomyces geotrichum, Pichia kudriavzevii,* and others (Gadaga et al. 2000, Dewan and Tamang 2006, Akabanda et al. 2013). *Koumiss* or *kumis* or *kumys* or *kymys* is a natural fermented dairy product of the Caucasian area. *Lb. casei, Lb. coryniformis, Lb. curvatus, Lb. helveticus, Lb. kefiranofaciens, Lb. kefiri, Lb. paracasei, Lb. plantarum, Lb. fermentum,* and *Leuc. mesenteroides* (Ying et al. 2004, Watanabe et al. 2008, Wu et al. 2009), *Lb. acidophilus, Lb. fermentum*, and *Lb. kefiranofaciens* (dominant LAB), *E. faecalis, Lc. lactis, Lb. buchneri, Lb. jensenii, Lb. kefiri, Lb. kitasatonis, Lb. paracasei, Leuc. mesenteroides*, and *Strep. thermophilus* (Hao et al. 2010), yeasts *Sacch. cerevisiae, Issatchenkia orientalis, Kazachstania unispora, Kl. marxianus, Pichia mandshurica* (Watanabe et al. 2008) were isolated from *koumiss*.

1.5.2 Fermented Cereal Foods

The well-documented fermented cereal foods of the world (Table 1.2) are sourdough of Europe, America, and Australia (de Vuyst et al. 2009), *selroti* of India and Nepal (Yonzan and Tamang 2009), *idli* of India and Sri Lanka (Sridevi et al. 2010), *dosa* of India and Sri Lanka (Soni et al. 1986), *mawè* and *gowé* of Benin (Vieira-Dalodé et al. 2007), *ben-saalga* of Burkino Faso and Ghana (Humblot and Guyot 2009), *kisra* of Sudan (Hamad et al. 1997), *kenkey* of Ghana (Oguntoyinbo et al. 2011), *togwa* of Tanzania (Mugula et al. 2003), *ting* of Botswana (Sekwati-Monang and Gänzle 2011), *ogi* and *kunu-zaki* of Nigeria (Oguntoyinbo et al. 2011), and *tarhana* of Turkey, Cyprus and Greece (Sengun et al. 2009). Cereal fermentation is characterized by a complex microbial ecosystem, mainly represented by the species of LAB and yeasts (Corsetti and Settanni 2007), whose fermentation confers to the resulting bread its characteristic features such as palatability and high sensory quality (Blandino et al. 2003). The species of *Enterococcus, Lactococcus, Lactobacillus, Leuconostoc, Pediococcus, Streptococcus,* and *Weissella* are commonly associated with cereal fermentation (Guyot 2010). A native strain of *Sacch. cerevisiae* is the principal yeast of most bread fermentations (Hammes et al. 2005). Other non-*Saccharomyces* yeasts are also significant in many cereal fermentations which include *Candida, Debaryomyces, Hansenula, Pichia, Trichosporon, Yarrowia* (Foschino et al. 2004, Veinocchi et al. 2006). *Lb. plantarum, Lb. panis, Lb. sanfrancisensis, Lb. pontis, Lb. brevis, Lb. curvatus, Lb. sakei, Lb. alimentarius, Lb. fructivorans, Lb. paralimentarius, Lb. pentosus, Lb. spicheri, Lb. crispatus, Lb. delbrueckii, Lb. fermentum, Lb. reuteri, Lb. acidophilus, Lc. lactis, Leuc. mesenteroides, Ped. pentosaceus, W. confuse*. The yeasts

Table 1.2 Some Common and Uncommon Ethnic Fermented Cereal Foods of the World

Product	*Raw Material/ Substrate*	*Sensory Property and Nature*	*Microorganisms*	*Country*	*References*
Abreh	Sorghum	Solid state and submerged	*Lb. plantarum*	Sudan	Odunfa and Oyewole (1997)
Aliha	Maize, sorghum	Nonalcoholic beverage	LAB	Ghana, Togo, Benin	Odunfa and Oyewole (1997)
Ambali	Millet, rice	Acidic, pan cake Shallow-fried, staple	LAB	India	Tamang (2010a)
Ang-kak	Red rice	Colorant	*Monascus purpureus*	China, Taiwan, Thailand, Phillipines	Steinkraus (1996)
Banku	Maize and cassava	Staple food	*Lactobacillus* sp., yeasts	Ghana	Campbell-Platt (1987)
Bahtura	Wheat flour	Deep-fried bread	LAB, yeasts	India	Campbell-Platt (1987)
Boza	Cereals	Sour refreshing liquid	*Lactobacillus* sp., *Lactococcus* sp., *Pediococcus* sp., *Leuconostoc* sp., *Sacch. cerevisiae*	Bulgaria, Balkan	Blandino et al. (2003)
Burukutu	Sorghum and cassava	Creamy, liquid, drink	*Sacch. cerevisiae, Sacch. chavelieri, Leuc. mesenteroides, Candida* sp., *Acetobacter* sp.	Nigeria	Odunfa and Oyewole (1997), Kolawole et al. (2013)
Busa	Maize, sorghum, millet	Submerged	*Sacch. cerevisiae, Schizosacchromyces pombe, Lb. plantarum ,Lb. helveticus, Lb. salivarius, Lb. casei, Lb. brevis, Lb. buchneri, Leuc. mesenteroides, Ped. damnosus*	East Africa, Kenya	Odunfa and Oyewole (1997), Blandino et al. (2003)

(Continued)

Table 1.2 (*Continued*) Some Common and Uncommon Ethnic Fermented Cereal Foods of the World

Product	*Raw Material/ Substrate*	*Sensory Property and Nature*	*Microorganisms*	*Country*	*References*
Ben-saalga	Pearl millet	Weaning food	*Lactobacillus* sp., *Pediococcus* sp., *Leuconostoc* sp., *Weissela* sp., yeasts	Burkina Faso, Ghana	Tou et al. (2007)
Chilra	Wheat, barley, buckwheat	Staple	LAB, *Sacch. cerevisiae*	India	Thakur et al. (2004)
Dégué	Millet	Condiment	*Lb. gasseri, Lb. fermentum, Lb. brevis, Lb. casei, Enterococcus* sp.	Burkina Faso	Abriouel et al. (2006)
Dosa	Rice and black gram	Thin, crisp pancake, Shallow-fried, staple	*Leuc. mesenteroides, Ent. faecalis, Tor. candida, Trichosporon pullulans*	India, Sri Lanka, Malaysia, Singapore	Soni et al. (1986)
Enjera/Injera	Tef flour, wheat	Acidic, sourdough, leavened, pancake-like bread, staple	*Lb. pontis, Lb. plantarum, Leuc. mesenteroides, Ped. cerevisiae, Sacch. cerevisiae, Cand. glabrata*	Ethiopia	Olasupo et al. (2010)
Gowé	Maize	Intermediate product used to prepare beverages, porridges	*Lb. fermentum, Lb. reuteri, Lb. brevis, Lb. confusus, Lb. curvatus, Lb. buchneri, Lb. salivarius, Lact. lactis, Ped. pentosaceus, Ped. acidilactici, Leuc. mesenteroides; Candida tropicalis, C. krusei, Kluyveromyces marxianus*	Benin	Vieira-Dalodé et al. (2007), Greppi et al. (2013a)
Hakua	Rice	Strong off-flavor, therapeutic uses	Unknown	Nepal, India	Tamang (2005)
Hopper	Rice, coconut water	Steak-baked, pancake, staple	*Sacch. cerevisiae*, LAB	Sri Lanka	Steinkraus (1996)
Hussuwa	Sorghum	Cooked dough	*Lb. fermentum, Ped. acidilactici, Ped. pentosaceus*, Yeasts	Sudan	Yousif et al. (2010)

Huitlacoche or 'maize mushroom'	cobs of pre-harvest maize	Large fruiting body edible, condiment	*Ustilago maydis*	Mexico	Alexandraki et al. (2013)
Hulumur	Sorghum, rice, millet	Nonalcoholic drink	*Leuc. mesenteroides, Lb. Plantarum, Lactobacillus* sp.	Sudan, Turkey	Campbell-Platt (1987)
Idli	Rice, blackgram dhal or other dehusked pulses	Mild-acidic, soft, moist, spongy pudding; staple, breakfast	*Leuc. mesenteroides, Lb. delbrueckii, Lb. fermenti, Lb. coryniformis, Ped. acidilactis, Ped. cerevisae, Streptococcus* sp., *Ent. faecalis, Lact. lactis, B. amyloliquefaciens, Cand. cacaoi, Cand. fragicola, Cand. glabrata, Cand. kefyr, Cand. pseudotropicalis, Cand. sake, Cand. tropicalis, Deb. hansenii, Deb. tamarii, Issatchenkia terricola, Rhiz. graminis, Sacch. cerevisiae, Tor. candida, Tor. holmii*	India, Sri Lanka, Malaysia, Singapore	Steinkraus et al. (1967), Sridevi et al. (2010)
Jalebi	Wheat flour	Crispy sweet, donut-like, deep-fried, snacks	*Sacch. Bayanus, Lb. fermentum, Lb. buchneri, Lact. lactis, Ent. faecalis, Sacch. cerevisiae*	India, Nepal, Pakistan	FAO (1999)
Kenkey	Maize	Acidic, solid, steamed dumpling, staple	*Lb. plantarum, Lb. brevis, Ent. cloacae, Acinetobacter* sp., *Sacch. cerevisiae, Cand. mycoderma*	Ghana	Odunfa and Oyewole (1997), Oguntoyinbo et al. (2011)
Khanom-jeen	Rice	Noodle, staple	*Lactobacillus* sp., *Streptococcus* sp., *Rhizopus* sp., *Mucor* sp.	Thailand	Blandino et al. (2003)
Khamak (Kao-mak)	Glutinous rice, *Look-pang* (starter)	Dessert	*Rhizopus* sp., *Mucor* sp., *Penicillum* sp., *Aspergillus* sp., *Endomycopsis* sp., *Hansenula* sp., *Saccharomyces* sp.	Thailand	Alexandraki et al. (2013)

(*Continued*)

Table 1.2 (*Continued*) Some Common and Uncommon Ethnic Fermented Cereal Foods of the World

Product	*Raw Material/ Substrate*	*Sensory Property and Nature*	*Microorganisms*	*Country*	*References*
Kichudok	Rice	Steamed cake, side dish	*Leuc. mesenteroides, Ent. faecalis, Saccharomyces* sp.	Korea	Von Mollendorff (2008)
Kunu-zaki	Maize, sorghum, millet	Mild-acidic, viscous, porridge, staple	*Lb. plantarum, Lb. pantheris, Lb. vaccinostercus, Corynebacterium* sp., *Aerobacter* sp., *Cand. mycoderma, Sacch. cerevisiae, Rhodotorula* sp., *Cephalosporium* sp., *Fusarium* sp., *Aspergillus* sp., *Penicillium* sp.	Nigeria	Oguntoyinbo et al. (2011)
Kisra	Sorghum	Thin pancake bread, staple	*Ped. pentosaceus, Lb. confusus, Lb. brevis, Lactobacillus* sp., *Erwinia ananas, Klebsiella pneumoniae, Ent. cloacae, Cand. intermedia, Deb. hansenii, Aspergillus* sp., *Penicillium* sp., *Fusarium* sp., *Rhizopus* sp.	Sudan	Mohammed et al. (1991), Hamad et al. (1997)
Kishk	Wheat, milk	Refreshing beverage	*Lb. plantarum, Lb. brevis, Lb. casei, B. subtilis*, Yeasts	Egypt	Blandino et al. (2003)
Koko	Maize	Porridge	*Ent. clocae, Acinetobacter* sp., *Lb. plantarum, Lb. brevis, Sacch. cerevisiae, Cand. mycoderma*	Ghana	Blandino et al. (2003)
Kunu-zaki	Maize (white and yellow), red sorghum	Mild, sour liquid/ porridge, staple	*W. confusa, Strep. lutetiensis, Strep. gallolyticus* subsp. *macedonicus,*	West Africa, Nigeria	Olasupo et al. (2010)
Lao-chao	Rice	Paste, soft, juicy, glurinous desert	*Rhiz. oryzae, Rhiz. Chinensis, Chlamydomucor oryzae, Sacchromycopsis* sp.	China	Blandino et al. (2003)

Maheu	Maize, sorghum, millet	Refreshing beverage	*Lb. delbrueckii*	South Africa	Steinkraus (2004)
Mahewu	Maize	Refreshing beverage	*Lb. delbruchi, Lact. lactis*	South Africa	Blandino et al. (2003)
Mawè	Maize	Intermediate product used to prepare beverages, porridges	*Lb. fermentum, Lb. reuteri, Lb. brevis, Lb. confusus, Lb. curvatus, Lb. buchneri, Lb. salivarius, Lact. lactis, Ped. pentosaceus, Ped. acidilactici, Leuc. mesenteroides; Candida glabrata, Sacch. cerevisiae, Kluyveromyces marxianus, Clavispora lusitaniae*	Benin, Togo	Hounhouigan et al. (1993), Greppi et al. (2013a,b)
Masvusvu	Maize	Refreshing beverage	LAB	Zimbabwe	Alexandraki et al. (2013)
Marchu	Wheat flour	Baked bread	Unknown	India, Pakistan	Tamang (2010a)
Mbege	Maize, sorghum, millet	Submerged	*Sacch. cerevisiae, Schizosaccharomyces pombe, Lb. plantarum, Leuc. mesenteroides*	Tanzania	Odunfa and Oyewole (1997)
Me	Rice	Acidic, sour, condiment	LAB	Vietnam	Alexandraki et al. (2013)
Minchin	Wheat gluten	Solid, condiment	*Paceilomyces* sp., *Aspergilus* sp., *Cladosporium* sp., *Fusarium* sp., *Syncephalastum* sp., *Penicillium* sp., *Trichothecium* sp.	China	Blandino et al. (2003)
Mungbean starch	Mungbean	Fermented noodle	*Leuc. mesenteroides*	Thailand	Alexandraki et al. (2013)

(*Continued*)

Table 1.2 (*Continued*) Some Common and Uncommon Ethnic Fermented Cereal Foods of the World

Product	*Raw Material/ Substrate*	*Sensory Property and Nature*	*Microorganisms*	*Country*	*References*
Naan	Wheat flour	Leaved bread, baked	*Sacch. cerevisiae*, LAB	India, Pakistan, Afghanistan	Batra (1986)
Ogi	Maize, sorghum, millet	Mild-acidic, viscous, porridge, staple	*Lb. plantarum, Lb. pantheris, Lb. vaccinostercus, Corynebacterium* sp., *Aerobacter* sp., *Candida krusei, Clavispora lusitaniae, Sacch. cerevisiae, Rhodotorula* sp., *Cephalosporium* sp., *Fusarium* sp., *Aspergillus* sp., *Penicillium* sp.	Nigeria	Odunfa and Oyewole (1997), Greppi et al. (2013a)
Perkarnaya	Rye	Acidic, aerated bread	Yeasts, LAB	Russia	Alexandraki et al. (2013)
Pito	Maize, sorghum, millet	Submerged	*Geotrichum candidum, Lactobacillus* sp., *Candida* sp.	West Africa	Odunfa and Oyewole (1997)
Poto poto (Gruel)	Maize	Slurry	*Lb. gasseri, Lb. plantarum/ paraplantarum, Lb. acidophilus, Lb. delbrueckii, Lb. reuteri, Lb. casei, Bacillus* sp., *Enterococcus* sp., yeasts	Congo	Abriouel et al. (2006)
Pozol	Maize	Mild-acidic, thick viscous, porridge, staple	*Lactobacillus* sp., *Leuconostoc* sp., *Candida* sp., *Enterobacteriaceae, B. cereus, Paracolobactrum aerogenoides, Agrobacterium azotophilum, Alkaligenes pozolis, E. coli* var. *napolitana, Pseudomonas mexicana, Kleb. pneumoniae, Saccharomyces* sp., molds	Mexico	FAO (1998)
Pumpernickel	Rye	Acidic, full-grain, aerated bread; long shelf-life	Yeasts, LAB, as for rye sourdough	Switzerland, Germany	Alexandraki et al. (2013)

Puto	Rice	Steamed cake, breakfast	*Leuc. mesenteroides, Ent. faecalis, Ped. cerevisiae*, yeasts	Philippines	Steinkraus (1996)
Rabadi	Buffalo or cow milk and cereals, pulses	Mild-acidic, thick slurry-like product	*Ped. acidilactici, Bacillus* sp., *Micrococcus* sp.; Yeasts	India, Pakistan	Ramakrishnan (1979), Gupta et al. (1992)
Sourdough bread	Rye	Sandwich, bread	*Lb. pontis* and *Lb. panis, Lb. amylovorus, Lb. acidophilus, Lb. crispatus, Lb. delbrueckii, Lb. fermentum, Lb. reuteri, Sacch. cerevisiae, Issatchenkia orientalis*	Germany, Northern Europe	Iacumin et al. (2009)
San Francisco	(Rye), mainly wheat	Mild-acidic, leavened bread	*Lb. sanfrancisensis, Lb. alimentarius, Lb. brevis, Lb. fructivorans, Lb. paralimentarius, Lb. pentosus, Lb. plantarum, Lb. pontis, Lb. spicheri, Leuc. mesenteroides, W. confusa*	USA	Gänzle et al. (1998)
Seera	Wheat grains	Dried, sweet dish	Unknown	India, Pakistan	Thakur et al. (2004)
Selroti	Rice-wheat flour-milk	Pretzel-like, deep-fried bread, staple	*Leuc. mesenteroides, Ent. faecium, Ped. pentosaceus* and *Lb. curvatus, Sacch. cerevisiae, Sacch. kluyveri, Deb. hansenii, P. burtonii, Zygosaccharomyces rouxii*	India, Nepal, Bhutan	Yonzan and Tamang (2010, 2013)
Siddu	Wheat flour, opium seeds, walnut	Steamed bread, oval-shaped, staple	*Sacch. cerevisiae, Cand. valida*	India	Thakur et al. (2004)
Sourdough bread	Rye, wheat	Mild-acidic, leavened bread	*Lb. sanfranciscensis, Lb. alimentarius, Lb. buchneri, Lb. casei, Lb. delbrueckii, Lb. fructivorans, Lb. plantarum, Lb. reuteri, Lb. johnsonii, Cand. humili, Issatchenkia orientalis*	America, Europe, Australia	de Vuyst et al. (2009)

(Continued)

Table 1.2 (*Continued*) Some Common and Uncommon Ethnic Fermented Cereal Foods of the World

Product	*Raw Material/ Substrate*	*Sensory Property and Nature*	*Microorganisms*	*Country*	*References*
Tapai Pulut	Glutinous rice, *Ragi*		*Chlamydomucor* sp., *Endomycopsis* sp., *Hansenula* sp.	Malaysia	Steinkraus (1996)
Tape Ketan	Glutinous rice, *Ragi*		*Thizopus* sp., *Chlamydomucor* sp., *Candida* sp., *Endomycopsis* sp., *Saccharomyces* sp.	Indonesia	Steinkraus (1996)
Tepache	Maize, pineapple, apple or orange		*B. subtilis, B. graveolus* and the yeasts, *Tor. insconspicna, Sacch. cerevisiae* and *Cand. queretana*	Mexico	FAO (1998)
Ting	Sorghum	Sour taste	LAB	Botswana	Sekwati-Monang and Gänzle (2011)
Togwa	Cassava, maize, sorghum, millet	Fermented gruel or beverage	*Lb. brevis, Lb. cellobiosus, Lb. fermentum, Lb. plantarum and Ped. pentosaceus, Candida pelliculosa, C. tropicalis, Issatchenkia orientalis, Sacch. cerevisiae*	Tanzania	Mugula et al. (2003)
Tarhana	Sheep milk, wheat	Mild-acidic, sweet-sour, soup or biscuit	*Lb. bulgaricus, Strep. thermophilus,* yeasts	Cyprus, Greece, Turkey	Karagozlu et al. (2008)
Taotjo	Wheat, rice, soybeans	Semi-solid food, condiment	*Asp. oryzae*	East Indies	Blandino et al. (2003)
Uji	Maize, sorghum, millet, cassava flour	Acidic, sour, porridge, staple	*Leuc. mesenteroides, Lb. plantarum*	Kenya, Uganda, Tanzania	Odunfa and Oyewole (1997)

Sacch. cerevisiae, Sacch. exiguus, Candida humilis, C. milleri, Issatchenkia orientalis were isolated from sourdough (Iacumin et al. 2009, Weckx et al. 2010). Gluten-free sourdough was prepared from buckwheat and/or teff flours using *Ped. pentosaceus, Leuc. holzapfelii, Lb. gallinarum, Lb. vaginalis, Lb. sakei, Lb. graminis, W. cibaria* (Moroni et al. 2011).

1.5.3 Fermented Vegetable Products

People eat plants, both domesticated and wild, preparing them according to a variety of recipes. Perishable and seasonal leafy vegetables, radish, cucumbers including young edible tender bamboo shoots are traditionally fermented into edible products using the indigenous knowledge of biopreservation. Mostly species of *Lactobacillus* and *Pediococcus*, followed by *Leuconostoc, Weisella, Tetragenococcus*, and *Lactococcus* (Watanabe et al. 2009a, Savadogo et al. 2011) have been isolated from various fermented vegetable foods of the world (Table 1.3). Species of LAB present in Korean *kimchi* are *Lc. lactis, Lb. brevis, Lb. curvatus, Lb. plantarum, Lb. sakei* subsp. *sakei, Luec. citreum, Leuc. gasicomitatum, Leuc. gelidum, Leuc. kimchii, Leuc. mesenteroides* subsp. *mesenteroides, Ped. pentosaceus, Weissella confusa, W. kimchii*, and *W. koreensis* (Shin et al. 2008, Nam et al. 2009, Park et al. 2010, Jung et al. 2011). A few species of non-LAB and yeasts were also reported from *kimchi* which included species of *Halococcus, Haloterrigena, Candida, Kluyveromyces, Lodderomyces, Natrialba, Natronococcus, Pichia, Saccharomyces, Sporisorium*, and *Trichosporon* (Chang et al. 2008). The species of LAB reported from *sauerkraut* are *Lc. lactis* subsp. *lactis, Lb. brevis, Lb. curvatus Lb. plantarum, Lb. sakei, Leuc. fallax, Leuc. mesenteroides* and *Ped. pentosaceus* (Johanningsmeier et al. 2007, Plengvidhya et al. 2007). *Lb. brevis, Lb. casei, Lb. casei* subsp. *pseudoplantarum, Lb. fermentum, Lb. plantarum, Leuc. fallax, Ped. pentosaceus* constitute the native lactic flora in the Himalayan fermented vegetables such as *gundruk, sinki, goyang, khalpi, inziangsang* (Karki et al. 1983, Tamang et al. 2005, Tamang and Tamang 2007, 2010). *Lb. brevis, Lb. lactis, Lb. fermentum, Lb. pentosus, Lb. plantarum, Leuc. mesenteroides* and *Ped. pentosaceus* are the functional LAB in *pao cai* or *suan cai*, the naturally fermented vegetable products of China and Taiwan (Yan et al. 2008, Huang et al. 2009). A complex microbial community in the brines of fermented olives based on a culture-independent study consisted of LAB (*Lb. pentosus/Lb. plantarum, Lb. paracollinoides, Lb. vaccinostercus/Lb. suebicus* and *Pediococcus* sp.), both cultivable and uncultivable non-lactics (*Gordonia* sp./*Pseudomonas* sp., *Halorubrum orientalis, Halosarcina pallid, Sphingomonas* sp./*Sphingobium* sp./*Sphingopyxis* sp., *Thalassomonas agarivorans*) and yeasts (*Candida* cf. *apicola, Pichia* sp., *Pic. manshurica/Pic. galeiformis, Sacch. cerevisiae*) (Abriouel et al. 2011).

Sunki is an ethnic nonsalted and fermented vegetable product of Japan prepared from the leaves and stems of the red turnip (Wacher et al. 2010). *Lb. plantarum, Lb. brevis, Lb. buchneri, Lb. kisonensis, Lb. otakiensis, Lb. rapi, Lb. sunkii,E. faecalis, B. coagulans*, and *P. pentosaceus* have been isolated from *sunki* (Endo et al. 2008, Watanabe et al. 2009a). *Fu-tsai* and *suan-tsai* are the ethnic fermented mustard products of Taiwan prepared by the Hakka tribes eaten as soup, fried with shredded meat, or stewed with meat (Chao et al. 2009). *Ped. pentosaceus* and *Tetragenococcus halophilus* (Chen et al. 2006), *Lb. farciminis, Leuc. mesenteroides, Leuc. pseudomesenteroides, W. cibaria*, and *W. paramesenteroides* (Chao et al. 2009), *Lb. futsaii* (Chao et al. 2012) are isolated from *fu-tsai* and *suan-tsai*.

Ent. durans,Lb. brevis, Lb. coryniformis, Lb. curvatus, Lb. delbrueckii, Lb. plantarum, Lb. xylosus, Leuc. citreum, Leuc. fallax, Leuc. lactis, Leuc. mesenteroides, Ped. pentosaceus, Tetra. halophilus were reported from Indian fermented bamboo shoots (Tamang and Sarkar 1996, Tamang et al. 2008, Tamang and Tamang 2009, Tamang et al. 2012, Sonar and Halami 2014). Species of *B. cereus, B. pumilus, B. subtilis* and *Pseudomonas fluorescens* along with LAB were also isolated

Goyang	Wild vegetable	Acidic, sour, wet, soup	*Lb. plantarum, L. brevis, Lact. lactis, Ent. faecium, Ped. pentosaceus, Candida* sp.	India, Nepal	Tamang and Tamang (2007)
Gundruk	Leafy vegetable	Acidic, sour, dry, soup, side-dish	*Lb. fermentum, Lb. plantarum, Lb. casei, Lb. casei* subsp. *pseudoplantarum, Ped. pentosaceus ,*	India, Nepal, Bhutan	Karki et al. (1983), Tamang et al. (2005)
Hirring	Bamboo shoot tips	Acidic, sour, wet, pickle	*Lb. brevis, Lb. plantarum, Lb. curvatus, Ped. pentosaceus, Leuc. mesenteroides, Leuc. fallax, Leuc. lactis, Leuc. citreum, Ent. durans, Lact. lactis*	India	Tamang and Tamang (2009)
Hom-dong	Red onion	Fermented red onion	*Leuc. mesenteroides, Ped. cerevisiae, Lb. plantarum, Lb. fermentum, Lb. buchneri*	Thailand	Phithakpol et al. (1995)
Hum-choy	Gai-choy	Chinese sauerkraut	*Pediococcus* sp., *Streptococcus* sp.,	China	Phithakpol et al. (1995)
Inziang-sang	Mustard leaves	Acidic, sour, dry, soup	*Lb. plantarum, Lb. brevis, Ped. acidilactici*	India	Tamang et al. (2005)
Jeruk	Fruits and vegetables	Acidic, wet	LAB	Malaysia	Merican (1996)
Jiang-sun	Bamboo shoot, salt, sugar, *douchi* (fermented soybeans)	Fermented bamboo, side dish	*Lb. plantarum, Ent. faecium, Lc. lactis* subsp. *lactis*	Taiwan	Chen et al. (2010)
Khalpi	Cucumber	Acidic, sour, wet, pickle	*Lb. brevis, Lb. plantarum, Ped. pentosaceus, Ped. Acidilactici, Leuc. Fallax*	India, Nepal	Tamang et al. (2005), Tamang and Tamang (2010)

(Continued)

Table 1.3 (*Continued*) Some Common and Uncommon Ethnic Fermented Vegetable Products of the World

Product	*Substrate/Raw Materials*	*Sensory Property and Nature*	*Microorganisms*	*Country*	*References*
Kimchi (beachoo)	Cabbage, green onion, hot pepper, ginger	Acidic, mild-sour, wet, side-dish	*Leuc. mesenteroides, Leuc. citreum, Leuc. gasicomitatum, Leuc. kimchii, Leuc. inhae, W. koreensis, W. cibaria, Lb. plantarum, Lb. sakei, Lb. delbrueckii, Lb. buchneri, Lb. brevis, Lb. fermentum, Ped. acidilactici, Ped. pentosaceus*	Korea	Nam et al. (2009), Jung (2012)
Kimchi (Dongchimi)	Radish, salt, water	Acidic, mild-sour, wet, soup, side-dish	*Leuc. mesenteroides, Lb. plantarum, Lb. brevis, Ped. cerevisiae*	Korea	Nam et al. (2009), Jung (2012)
Kimchi (Kakdugi)	Radish, salt, garlic, green onion, hot pepper, ginger	Acidic, mild-sour, wet, side-dish	*Leuc. mesenteroides, , Lb. plantarum, Lb. brevis, Ped. cerevisiae*	Korea	Nam et al. (2009), Jung (2012)
Lung-siej	Bamboo shoot	Sour-acidic, soft	*Lb. brevis, Lb. plantarum, Lb. curvatus, Ped. pentosaceus, Leuc. mesenteroides, Leuc. fallax, Leuc. lactis, Leuc. citreum, Ent. durans*	India	Tamang (2010a)
Naw-mai-dong	Bamboo shoots	Acidic, wet	*Leuc. mesenteroides, Ped. cerevisiae, Lb. plantarum, Lb. brevis, Lb. fermentum, Lb. buchneri*	Thailand	Phithakpol et al. (1995)
Mesu	Bamboo shoot	Acidic, sour, wet	*Lb. plantarum, Lb. brevis, Lb. curvatus, Leu, citreum, Ped. pentosaceus*	India, Nepal, Bhutan	Tamang and Sarkar (1996), Tamang et al. (2008)
Oiji	Cucumber, salt, water	Fermented cucumber	*Leuc. mesenteroides, Lb. brevis, Lb. plantarum, Ped. cerevisiae*	Korea	Alexandraki et al. (2013)

Olives (fermented)	Olive	Acidic, wet, Salad, side dish	*Leuc. mesenteroides, Ped. pentosaceus; Lb. plantarum Lb. pentosus/Lb. plantarum, Lb. paracollinoides, Lb. vaccinostercus/ Lb. suebicus* and *Pediococcus* sp. non-lactics (*Gordonia* sp./*Pseudomonas* sp., *Halorubrum orientalis, Halosarcina pallid, Sphingomonas* sp./ *Sphingobium* sp./*Sphingopyxis* sp., *Thalassomonas agarivorans*) and yeasts (*Candida* cf. *apicola, Pichia* sp., *Pic. manshurica/Pic. galeiformis, Sacch. cerevisiae*)	USA, Spain, Portugal, Peru, Chile	Abriouel et al. (2011)
Pak-gard-dong	Leafy vegetable, salt, boiled rice	Acidic, wet, side dish	*Lb. plantarum, Lb. brevis, Ped. cerevisiae*	Thailand	Phithakpol et al. (1995)
Pak-sian-dong	Leaves of *Gynandropis pentaphylla*	Acidic, wet, side dish	*Leuc. mesenteroides, Ped. cerevisiae, Lb. plantarum, Lb. germentum, Lb. buchneri*	Thailand	Phithakpol et al. (1995)
Poi	Taro corms	Acidic, semi-solid	LAB, yeasts	Hawaii	Alexandraki et al. (2013)
Pao cai	Cabbage	Sweet and sour rather than spicy, breakfast	*Lb. pentosus, Lb. plantarum, Lb. brevis, Lb. lactis, Lb. fermentum, and Leuc. mesenteroides*, and *Ped. pentosaceus*	China	Yan et al. (2008)
Sauerkraut	Cabbage	Acidic, sour, wet, salad, side dish	*Leuc. mesenteroides, Ped. pentosaceus; Lb. brevis, Lb. plantarum, Lb. sakei*	Europe, USA, Canada, Australia	Johanningsmeier et al. (2007)

(*Continued*)

Table 1.3 (*Continued*) Some Common and Uncommon Ethnic Fermented Vegetable Products of the World

Product	*Substrate/Raw Materials*	*Sensory Property and Nature*	*Microorganisms*	*Country*	*References*
Sayur asin	Mustard leaves, cabbage, salt, coconut	Acidic, sour, wet, salad	*Leuc. mesenteroides, Lb. plantarum, Lb. brevis, Lb. confuses, Ped. pentosaceus*	Indonesia	Puspito and Fleet (1985)
Sinnamani	Radish	Acidic, sour, wet	LAB	Nepal	Tamang (2010a)
Soibum	Bamboo shoot	Acidic, sour, soft, curry	*Lb. plantarum, Lb. brevis, Lb. coryniformis, Lb. delbrueckii, Leuc. fallax, Leuc. Lact. lactis, Leuc. mesenteroides, Ent. durans, Strep. lactis, B. subtilis, B. lichniformis, B. coagulans, B. cereus, B. pumilus Pseudomonas fluorescens, Saccharomyces* sp., *Torulopsis* sp.	India	Jeyaram et al. (2009), Tamang et al. (2012)
Soidon	Bamboo shoot tips	Acidic, sour, soft, curry	*Lb. brevis, Leuc. fallax, Lact. lactis*	India	Tamang et al. (2008)
Soijim	Bamboo shoot	Acidic,liquid, condiment	*Lb. brevis, Lb. plantarum, Lb. curvatus, Ped. pentosaceus, Leuc. mesenteroides, Leuc. fallax, Leuc. lactis, Leuc. citreum, Ent. durans*	India	Tamang et al. (2008)
Sinki	Radish tap-root	Acidic, sour, dry, soup, pickle	*Lb. plantarum, Lb. brevis, Lb. casei, Leuc. fallax*	India, Nepal, Bhutan	Tamang and Sarkar (1993), Tamang et al. (2005)
Suan-cai	Vegetables	Acidic, sour, wet	*Ped. pentosaceus, Tetragenococcus halophilus*	China	Chen et al. (2006)

Suan-tsai	Mustard	Acidic, sour, dry	*Ent. faecalis, Lb. alimentarius, Lb. brevis, Lb. coryniformis, Lb. farciminis, Lb. plantarum, Lb. versmoldensis, Leuc. citreum, Leuc. mesenteroides, Leuc. pseudomesenteroides, Ped. pentosaceus, W. cibaria, W. paramesenteroides*	Taiwan	Chao et al. (2009)
Sunki	Turnip	Acidic, sour, wet	*Lb. plantarum, Lb. fermentum, Lb. delbrueckii, Lb. parabuchneri, Lb. kisonensis, Lb. otakiensis, Lb. rapi, Lb. sunkii*	Japan	Endo et al. (2008), Watanabe et al. (2009a)
Takuanzuke	Japanese radish, salt, sugar, *Shochu*	Pickle radish	*Lb. plantarum, Lb. brevis, Leuc. mesenteroides, Streptococcus* sp., *Pediococcus* sp., yeasts	Japan	Alexandraki et al. (2013)
Takanazuke	Broad leaved mustard, red pepper, salt, turmeric	Vegetable pickle Takuanzuke	*Ped. halophilus, Lb. plantarum, Lb. brevis*	Japan	Alexandraki et al. (2013)
Tuaithur	Bamboo shoot	Solid, wet, sour, curry	*Lb. plantarum, Lb. brevis, Ped. pentosaceou, Lc. lactis, Bacillus circulans, B. firmus, B. sphaericus, B. subtilis*	India	Chakrabarty et al. (2014)
Tuairoi	Bamboo shoot	Solid, dry, sour, curry	*Lb. plantarum, Ent. faecium, Ped. pentosaceous, Leuc. mesenteroides, B. laterosporus, B. circulans, B. stearothermophilus, B. firmus, B. cereus*	India	Chakrabarty et al. (2014)
Yan-Jiang	Ginger	Pickle	LAB	Taiwan	Chang et al. (2011)