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Ethnic fermented foods of the world: an overview

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Abstract

The origins of traditional fermented foods and the types and characteristics of fermented foods by region are reviewed. Fermented foods are classified into alcohol fermentation, acid fermentation, carbon dioxide (bread) fermentation, and amino acid/peptide fermentation, and related fermentation technologies for each region are introduced. The raw materials, microorganisms involved, and usage of ethnic fermented foods are reviewed and compared one another. The beginning of food fermentation technology is related to the invention and use of earthenware, and Northeast Asia is presumed to be one of the birth places. During the period of primitive pottery culture (8000–3000 BCE) on the Korean Peninsula and the coastal region of Korea Strait, boiling technology of food materials using pottery and salt manufacturing technology from seawater were developed, and at the same time, alcohol fermentation using grains and salt-fermentation of fish and vegetables emerged. In the West, where people were nomads, a roasting/grilling culture was continued for a long time, and technologies for fermenting fruit wine and milk products such as cheese and yogurt were developed. As a result, fermentation was mainly used for enhancing the taste of plant foods in the East, while for extending the shelf life of animal foods in the West. The production of salty and meaty flavors from soybeans and marine products by fermentation in East Asia is a technology that increases the value of low-quality proteins.

Keywords Early history of food fermentation, Classification of fermented foods, Microorganisms in ethnic fermented foods, World map of fermented foods

Early history of food fermentation

Traditional food fermentation technologies are based on the natural process whereby wet food ingredients undergo microbial degradation. The products that are edible at the end of this process are termed as fermented food, and the non-edible products are termed as spoiled or putrid food. Humans have acquired fermentation skills over a long period of time and have developed unique technologies that are suited to specific environments and raw materials available in different regions of the world.

The first discovered fermentation product may have been alcoholic fermented fruits where the sugars contained in the fruit were fermented by natural yeast to produce alcohol. More fermented products were likely produced when earthenware was invented for holding water or wet foods [1, 2].

The oldest piece of pottery discovered thus far was found in the Yuchanyan Cave along the Yangtze River in South China and is dated between 18,300 and 15,300 YBP [3]. In North China, the oldest Paleolithic earthenware remains are estimated to have originated at 12,000 BCE. In far east Russia, fragments of earthenware that are dated at 10,000 BCE were excavated from the ruins of Gasya and Khummy in the Amur River basin [4]. Pottery fragments estimated to date back to 10,000 BCE have also been found in Fukui Cave in Kyushu, southern Japan, and Kamikuroiwa Cave in Shikoku [5].

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The oldest primitive pottery excavated in Korea is from the Gosan-ri site in the Jeju Island and is estimated to be from approximately 8000 BCE. Fragments of patternless (*Mumun*) pottery dating back to 6000 BCE have also been excavated from many shell mounds along the southern and eastern coasts of South Korea [6]. Primitive Mumun and thin-line uplifted (*Yunggimun*) pottery were excavated from the lower parts of the comb-patterned (*Jeulmun*) pottery layer in the Dongsam-dong, Sangnodaedo, and Seopohang ruins along the coast of the Korea Strait [7]. Since earthenware buried in these shell mounds disintegrate into the soil faster than in a humid soil environment, the age of pottery usage along the coast of the Korea Strait is estimated to be the same as that of primitive earthenware from China or the Maritime Province (Fig. 1) [6].

Archaeologists have conducted in-depth research on the shapes, patterns, and ages of earthenware; however,

food scientists consider pottery to be humankind's first bioreactor. Before the invention of pottery, people had no means of boiling water. However, pottery usage permitted wet food to be stored for long periods of time and boiled over fire. Storing wet food in earthenware promoted the proliferation of microorganisms, causing spoilage or fermentation. In contrast, using pottery over fire to boil plants or animal flesh inside it, transforms the ingredients into delicious food.

The manufacture and use of pottery may have begun as early as 8000 BCE in sedentary areas along the coasts of the Korea Strait, and not until later did techniques improve far enough for earthenware to be used for cooking or storing liquids. Pottery came into use long before the farming culture flourished in this region [8]. The long tradition of the Korean people in Northeast Asia engaging in a culture of preparing boiled food, such as *Tang* (Korean soup) and *Jjigae* (Korean stew), and fermented

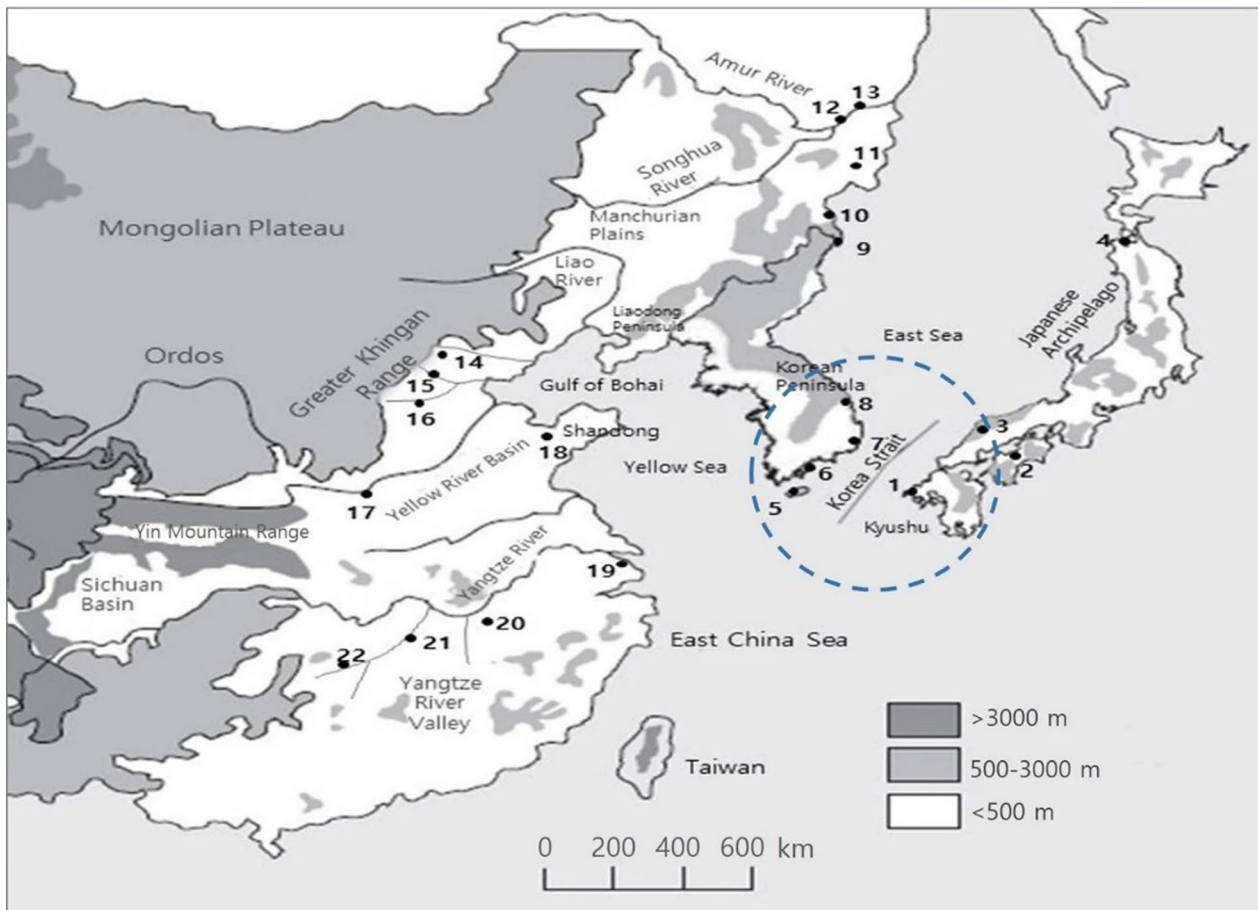


Fig. 1 Primitive earthenware excavation sites in Northeast Asia [6]

products supports the hypothesis that this region was the birthplace of primitive pottery culture [6].

Human beings are estimated to have discovered salt-making by boiling seawater in earthenware during primitive pottery culture at approximately 8000–6000 BCE in Northeast Asia and may have concurrently developed fish fermentation technology and kimchi fermentation from vegetables [6]. In contrast, using cereals to produce alcohol was developed later; for example, production of beer in Egypt and rice wine in Northeast Asia are dated to have occurred at approximately 4000 BCE [2, 9]. The oldest known written recipe for beer was found on a 4000-year-old Mesopotamian clay tablet [9]. The Babylonians produced 16 types of beer using barley, wheat, and honey. The Chinese book *Shijing* (1100–60 BC) has a poem describing a ‘thousand wines of Yao’, a legendary nation of China at approximately 2300 BC. Thus, fermentation appears to be a technology invented in Northeast Asia

by littoral foragers of the Primitive Pottery Age (8000–3000 BC) before the advent of agriculture [6, 8].

Classification of traditional fermentation technology

Traditionally, fermented foods can be classified according to the materials obtained from bioconversion such as alcohol fermentation, acid fermentation, carbon dioxide (bread) fermentation, and amino acid/peptide fermentation from proteins [8, 10]. Numerous varieties of fermented food can be prepared in each fermentation class depending on the raw materials used [11]. For example, alcohol fermentation can be used to prepare wine from grapes, cider from apple, toddy from palm sap, beer from barley or corn, *chongju* from rice, and *mayichu* from horse milk. Furthermore, brandy, rum, vodka, whisky, and soju are produced using distillation. Figure 2 presents a map of traditional fermented foods worldwide [2].

Traditional societies can be classified based on the indigenous fermented foods they produce; for example,

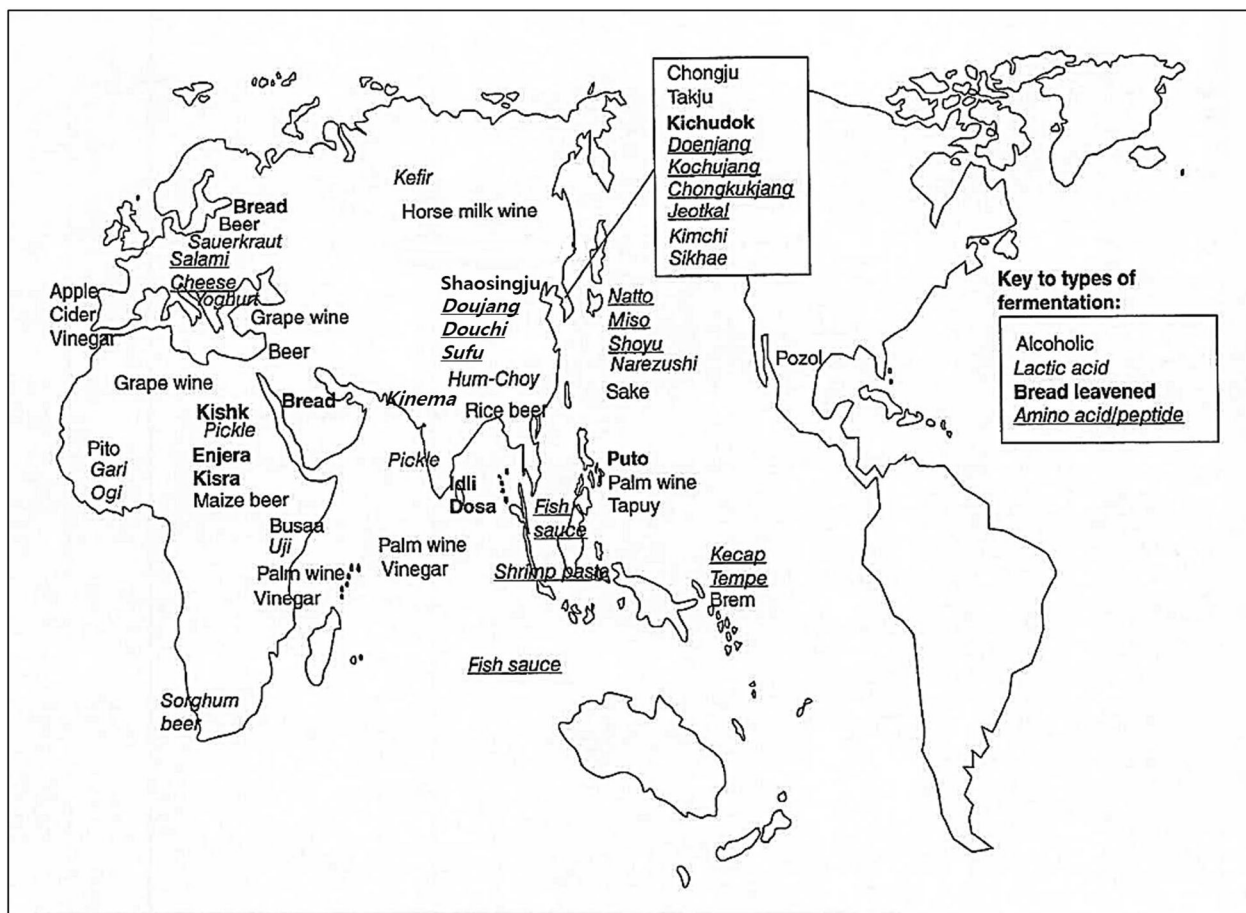


Fig. 2 Map of traditional fermented foods worldwide [2]

the cheese/yogurt culture of the Middle East, Northern Africa, and Europe; the fish sauce culture of Southeast Asia; and the soybean sauce culture of Northeast Asia. These products, which are imbued with the umami (meaty) taste of amino acids and peptides are produced by the breakdown of proteins, and the basic flavor of meals and condiments characterize the dietary culture of these different regions.

Alcoholic beverages

Alcoholic beverages have played an important role in human spiritual and cultural life in both Western and Eastern societies. Unlike in Europe and the Middle East, where most indigenous alcoholic beverages are produced from fruits, alcoholic beverages are produced from cereals in the Asia–Pacific region and serve as important sources of nutrients. European beer uses barley malt as the major raw material, whereas Asian alcoholic beverages use mold-grown *nuruk* made from rice or wheat as the fermentation starter.

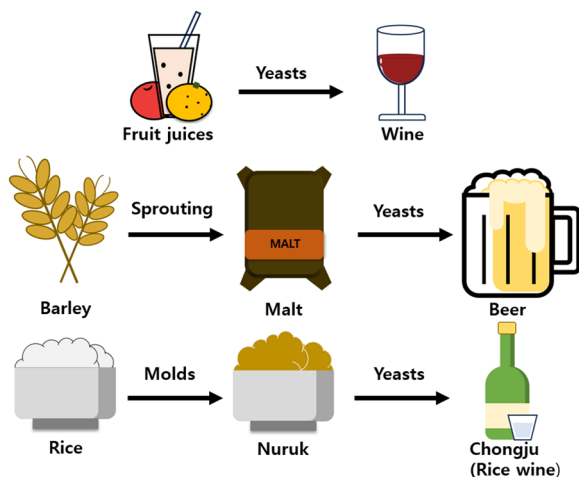


Fig. 3 The general processes of alcohol fermentation in wine, beer, and rice wine

Alcohol is produced from glucose by the alcohol-producing yeast *Saccharomyces cerevisiae*. The general processes of alcohol fermentation in wine, beer, and rice wine are shown in Fig. 3.

Malt contains amylases that breakdown starch into fermentable sugars. In Korea, the fermentation starter is known as *nuruk*. It is prepared by growing molds on cereals that are either raw or cooked to digest starch into sugars that are then consumed by yeast to produce alcohol. Therefore, rice wine fermentation is a two-step fermentation process. Table 1 summarizes the names of the cereal fermentation starters used in the Asia–Pacific region, their ingredients, and the microorganisms involved [2, 12].

Wine

Wine is the fermented product of grapes that are primarily cultivars of *Vitis vinifera*. The fermented juices of other fruits such as apples, berries, peaches, and herbs, are also called wine. The distinctive characteristics of various wines depend on the composition of the raw material, nature of the fermentation process, and the processing and aging treatments used. Table wines with excess carbon dioxide include white, pink, and red sparkling wines with or without a muscat flavor (such as champagne, spumante, and Sekt). Non-sparkling white table wines are dry or sweet with regional, varietal, and proprietary names (such as Riesling, Chardonnay, Chablis, and Sauternes). Pink and red table wines are among the most important in terms of consumption volume or consumer demand and have varietal, regional, and proprietary names (such as Cabernet Sauvignon, Pinot Noir, Burgundy, and Bordeaux). Numerous dessert wines are named after the grape variety from which they are produced, and the production processes involve and the addition of flavors and herbs [13].

Table 1 Fermentation starters and their major ingredients in different countries [2, 12]

Country	Name	Commonly used ingredients	Shape	Microorganisms
China	Chu (Qu)	Wheat, barley, millet, and rice (whole grain, grits, flour, or cake)	Granular	<i>Rhizopus</i> and <i>Amylomyces</i>
Korea	Nuruk	Wheat, rice, and barley (whole grain, grits, or flour)	Large cake	<i>Aspergillus</i> , <i>Rhizopus</i> , and yeasts
Japan	Koji	Wheat, rice (whole grain, grits, or flour)	Granular	<i>Aspergillus</i>
Indonesia	Ragi	Rice (flour)	Small cake	<i>Amylomyces</i> and <i>Endomycopsis</i>
Malaysia	Ragi	Rice (flour)	Small cake	No data available
Philippines	Bubod	Rice and glutinous rice (flour)	Small cake	<i>Mucor</i> , <i>Rhizopus</i> , and <i>Saccharomyces</i>
Thailand	Loogpang	Bran	Powder	<i>Amylomyces</i> and <i>Aspergillus</i>
India	Marchaa	Rice	Flat cake	<i>Hansenular</i> , <i>Mucor</i> , and <i>Rhizopus</i>

Beer

Beer is an alcoholic beverage derived from barley malt with or without the addition of other cereal grains (rice, corn, sorghum, and wheat) and flavored with hops. Malt is prepared in three steps: barley steeping, germination, and drying. Storing steeped barley under a humid (45% moisture) and dark condition for 4–6 days induces barley germination and the production of starches, splitting enzymes, α -amylase, β -amylase, protease, and cellulase. Next, the malt is dried, and germination is terminated by roasting the grains in a kiln. The duration of roasting affects the color and flavor of the malt. A short roast yields a malt of light golden color and mild flavor. This malt is used to brew light beers such as lagers. In contrast, a longer roast results in a much darker grain with a much stronger toasted or burnt flavor. It is used to brew stronger beers such as ale, bitter (heavy to the Scots), and stout. The malt is coarse milled to form “grist” that can be transported to the brewery and/or stored. Drying stabilizes malt and enables year-round beer production worldwide, even in places where barley is not grown. This differs from wine production, which is only possible seasonally and in proximity to grape-growing areas.

Beer production involves three distinct stages, namely brewing, fermentation, and finishing. An extract of crushed malt and selected grains is used to prepared wort. The approximate time and temperature for wort preparation are 4–10 h and 50 °C, respectively. This step is often referred to as brewing. The mashing temperature and duration vary depending on the mashing system. Mashing converts insoluble starch into fermentable sugars (maltose and glucose) and proteins into peptides and amino acids. The converted mash is filtered to separate the liquid (wort) and insoluble husk. The clear wort is boiled in a kettle. Hops are added during the heating period. The insoluble humulones in hops undergo a chemical rearrangement during this process to form isohumulones, which enables them to dissolve in water and impart a palate-cleansing bitterness that imparts the unusual drinkability to beer [9].

The next stage is fermentation, which involves the conversion of wort into beer by yeast. Yeast is added to cooled wort that contain oxygen, fermentable sugars, and various nutrients including amino acids. The two main types of beer—lager and ale—are fermented using different yeast strains. Lager is produced by the bottom-fermenting *Saccharomyces uvarum* (*carlsbergensis*) at fermentation temperatures of 7–15 °C. At the end of fermentation, the yeasts flocculate and collect at the bottom of the fermenter. Ale is produced by the top-fermenting yeast *S. cerevisiae* at fermentation temperatures 18–22 °C. *S. cerevisiae* is less flocculent and collects at the surface of the fermenting wort, from where they are

collected for reuse. The differentiation of lagers and ales on the basis of bottom and top cropping has become less distinct with the advent of vertical conical bottom fermenters and centrifuges.

Fermented beers are prepared in several ways. The simplest and most widely used method is to transfer beer to another tank, chilling it en route, and store it for 7–14 days, which is known as ‘rest.’ During this period most of the suspended yeast settle, and the harsh sulfury notes and undesirable flavor compounds (notably diacetyl) are removed. After completion of the rest period, cold beer is filtered using diatomaceous earth as the filter medium. To achieve sterile filtration where all yeast and lactobacilli are removed, another diatomaceous earth filter, cotton fibers, a porous plastic sheet, or a ceramic filter are used as retaining barriers. If packaged beer is not sterilized, it has to be pasteurized because beer is a fertile medium for the growth of a range of microbes. Pasteurization may be performed just before filling (bulk pasteurization) or after filling in long tunnels with hot water sprays (tunnel pasteurization). Bulk pasteurization is performed for approximately 1 min, whereas tunnel pasteurization is performed for approximately 1 h [14].

Rice wine

Rice wine is the generic name for alcoholic beverages made from cereals (primarily rice) in East Asia. Traditional alcoholic beverages vary from crystal-clear products to turbid liquids or thick gruels and pastes. Clear products, known as *shaosingjiu* in China, *chongju* in Korea, and *sake* in Japan, contain approximately 15% alcohol and are designated as rice wine. Turbid beverages such as *takju* in Korea and *tapuy* in the Philippines that contain less than 8% alcohol, suspended insoluble solids, and live yeasts and are referred to as rice beer. Alcoholic beverages prepared from cereals in the Asia–Pacific region are listed in Table 2 [2, 8].

The process of cereal-based alcohol fermentation using *nuruk* occurs in a two-step fermentation process: a solid-state fermentation where mold is grown on raw or cooked cereals to yield the *nuruk*, and mashing of the *nuruk* with additional cereals to produce alcohol using yeast [8]. The dried and powdered *nuruk* is mixed with water and stored in a cool place for several days to prepare a “mother” brew. During this period, microbial amylases and proteases are activated, and they convert starch into sugars. The acid-forming bacteria in *nuruk* produce organic acids, which reduces the pH to <4.5. Approximately 2–3 volumes of cooked grain and water are added to the mother brew to prepare the first fermentation mash. This addition increases the production volume and enhances the alcohol concentration and quality of the final product. Preparation of multiple

Table 2 Cereal-based alcoholic beverages in the Asia–Pacific region [8]

Product	Country	Primary ingredients	Microorganisms	Appearance and usage
<i>Rice wine</i>				
Shaosingjiu	China	Rice	<i>S. cerevisiae</i>	Clear liquid
Chongju	Korea	Rice	<i>S. cerevisiae</i>	Clear liquid
Sake	Japan	Rice	<i>Saccharomyces sake</i>	Clear liquid
<i>Rice beer</i>				
Takju	Korea	Rice and wheat	Lactic acid bacteria, <i>S. cerevisiae</i>	Turbid liquid
Tapuy	Philippines	Rice and glutinous rice	<i>Saccharomyces</i> , <i>Mucor</i> , <i>Rhizopus</i> , <i>Aspergillus</i> , <i>Leuconostoc</i> , <i>Lactobacillus plantarum</i>	Sour, sweet liquid, Paste
Brem bali	Indonesia	Glutinous rice	<i>Mucor indicus</i> , <i>Candida</i>	Dark brown liquid, alcoholic
<i>Alcoholic rice paste</i>				
Khaomak	Thailand	Glutinous rice	<i>Rhizopus</i> , <i>Mucor</i> , <i>Saccharomyces</i>	Semi-solid, sweet, alcoholic
Tapai pulut	Malaysia	Glutinous rice	<i>Chlamydo mucor</i> , <i>Hansenula</i>	Semi-solid, sweet, alcoholic
Tape-kekan	Indonesia	Glutinous rice	<i>Aspergillus rouxii</i> , <i>Saccharomycopsis</i> , <i>Burtonii</i>	Sweet/sour, alcoholic paste
Lao-chao	China	Rice	<i>Rhizopus</i> , <i>A. rouxii</i>	Paste
<i>Alcoholic rice Seasoning</i>				
Mirin	Japan	Rice, alcohol	<i>Aspergillus oryzae</i> , <i>Aspergillus usamii</i>	Clear liquid seasoning

brews prepared by adding two, three, four, or nine times the quantity of newly cooked grains to the fermenting mash have been described previously [1, 15].

Newly cooked cereals are added at the end of each fermentation step. The incubation period for each step of the brewing process varies from 2 days to 1 month depending on the fermentation temperature. Low temperatures (ca. 10 °C) are better for improving the taste and maintaining the quality of rice wine. Traditionally, rice wines are prepared in late autumn or early spring when the ambient temperatures are below 10 °C in the far east Asian countries. The volume of wine produced is approximately the same as that produced from the raw grains [16].

Rice beers are produced at a higher fermentation temperature (ca. 20 °C). The fermentation starter powder is mixed with cooked cereals (rice, wheat, barley, or corn) and water and incubated at approximately 20 °C for 2–3 days, followed by filtration using a fine-mesh sieve or cloth. Beers are usually prepared using either a single or double brew. Cereal beers are abundant in micronutrients such as vitamin B groups that are formed during fermentation; these provide rapid energy supplementation with ethyl alcohol and partially hydrolyzed polysaccharides [12].

Acid-fermented foods

Lactic acid fermentation was probably one of the first biological processes through which human beings discovered the benefits of fermentation [2, 17]. Sour fermentations of flour dough, milk, cereals, and vegetables have

been used to enhance food quality and palatability since prehistoric times. The fermentation of dairy products in Europe has been widely studied over the past century, and these processes have been highly standardized and industrialized to ensure the efficient production of safe and nutritious food products. Caucasian yogurt and Middle Eastern cheese are now foods that are consumed day-to-day in Europe, America, and Oceania and are considered gourmet foods for wealthy people in Asia and Africa. However, little scientific research has been conducted on other types of fermented foods that have contributed greatly to diets in East Asia and Africa [18].

The most important microorganisms in acid-fermented foods are lactic acid bacteria, which are classified into four genera: *Streptococcus*, *Pediococcus*, *Lactobacillus*, and *Leuconostoc*. Additionally, *Bifidobacterium*, which belongs to the order *Actinomycetales*, is vital for producing dairy products. *Streptococcus*, *Pediococcus*, and some *Lactobacillus* are homolactic, whereas *Leuconostoc* and *Bifidobacterium* are heterolactic. The metabolic pathways of glucose in lactic acid bacteria include glycolysis, the bifidus pathway, and the 6-P-gluconate pathway.

Lactic acid-fermented milk products

Cultured milk products are produced through the lactic acid fermentation of milk using various bacterial cultures. Fermented milk products originated in the Near East and have spread to parts of Southern and Eastern Europe. Today, various forms of cultured milk products have been introduced worldwide, including in regions where milk is not a traditional food such as Korea and

Japan. Cultured milk products vary greatly depending on variations in the starter cultures used and manufacturing principles. However, most cultured products are prepared via the following basic manufacturing steps written below.

First, the preparation of the starter culture is essential. This step involves growing specific bacteria that will initiate the fermentation process. Next, the cultured milk product undergoes several treatment processes such as pasteurization for eliminating harmful bacteria, separation for adjusting fat content, and homogenization to ensure uniform texture. After then, it is inoculated with the prepared bacterial cultures. This step introduces the necessary microorganisms into the milk. The inoculated milk is then incubated at a controlled temperature, allowing the bacteria to ferment the lactose in the milk, producing lactic acid. This fermentation process thickens the milk and imparts a tangy flavor. Following incubation, the fermented milk is agitated to achieve a smooth consistency and cooled to stop the fermentation process. Finally, the cultured milk product is packaged for distribution and sale. The principal cultured milk products worldwide, including their type, location, and the bacterial culture used, are listed in Table 3 [2, 19].

Lactic acid-fermented cereals and starchy tubers

Lactic acid fermentation of bread dough improves the quality and flavor of baked products. It also enhances the palatability of bread that has been made from low-grade flours or underutilized cereals. Acid-fermented breads and pancakes are important staple foods for people in Africa, some parts of Europe, and Asia [19]. Sour bread is a typical German food, and Scandinavian rye bread is highly favored by Nordic people. The Indian *idli* bread types (*idli*, *dosa*, *dhokla*, and *khaman*) are important staple foods of the Indian and Sri Lankan people and are consumed three or four times a week at breakfast and supper. *Idli* is a small, white, acid-leavened, steamed cake. It is made from a thick batter, which is prepared from rice and dehulled black gram and subjected to bacterial fermentation. Similar products are produced from rice in the Philippines (*puto*) and Korea (*kichudok*). *Puto* is prepared using year-old rice, and the batter is neutralized during fermentation. In Sri Lanka, the *hopper* is prepared from acid-fermented dough made from rice, wheat, and coconut water. During hopper fermentation, a large inoculum of baker's yeast or coconut toddy, which contains acid-producing bacteria, is added. Table 4 lists various types of acid-fermented bread, pancakes, porridges, and starch-based foods consumed in different regions [2, 18].

Table 3 Cultured milk products [19]

Product	Location	Bacteria
Acidophilus	Europe and North America	<i>Lactobacillus acidophilus</i> and <i>Bifidobacterium bifidum</i>
Bulgarian, buttermilk	Europe	<i>Lactobacillus bulgaricus</i>
Buttermilk	North America, Europe, Middle East, North Africa, Indian Subcontinent, and Oceania	<i>Lactobacillus lactis</i> subsp. <i>cremoris</i> , <i>L. lactis</i> subsp., <i>Diacetyllactis</i> , and <i>Leuconostoc cremoris</i>
Flimjolk	Europe	<i>Lactococcus lactis</i> subsp. <i>cremoris</i> , <i>L. lactis</i> , <i>L. lactis</i> subsp. <i>diacetyllactis</i> , <i>L. cremoris</i> , <i>Alcaligenes viscosus</i> , and <i>Geotrichum candidum</i>
Flummary	Europe and South Africa	Naturally present lactic bacteria
Ghee	Indian subcontinent, Middle East, South Africa, and Southeast Asia	<i>Streptococcus</i> , <i>Lactobacillus</i> , and <i>Leuconostoc</i> spp.
Junke	Europe	<i>Lactococcus</i> and <i>Lactobacillus</i> spp.
Kefir	Middle East, Europe, and North Africa	<i>Streptococcus</i> , <i>Lactobacillus</i> , and <i>Leuconostoc</i> spp., <i>Candida kefir</i> , and <i>Kluyveromyces fragilis</i>
Kishk	North Africa, Middle East, Europe, Indian subcontinent, and East Asia	<i>Streptococcus</i> , <i>Lactobacillus</i> , and <i>Leuconostoc</i> spp.
Kolatchen	Middle East and Europe	<i>L. lactis</i> , <i>L. lactis</i> subsp. <i>diacetyllactis</i> , <i>L. lactis</i> subsp. <i>cremoris</i> , and <i>S. cerevisiae</i>
Koumiss	Europe, Middle East, and East Asia	<i>L. lactis</i> , <i>L. bulgaricus</i> , <i>Candida kefir</i> , and <i>Torulopsis</i>
Kurut	North Africa, Middle East, Indian subcontinent, and East Asia	<i>Lactobacillus</i> and <i>Streptococcus</i> spp., <i>Saccharomyces lactis</i> , and <i>Penicillium</i>
Lassi	Indian subcontinent, East Asia, Middle East, North Africa, South Africa, and Europe	<i>Streptococcus thermophilus</i> , <i>L. bulgaricus</i> , sometimes yeast
Prokllada	Europe	<i>Streptococcus</i> and <i>Lactobacillus</i> sp.
Sour cream	Europe, North America, Indian subcontinent, and Middle East	<i>L. lactis</i> subsp. <i>cremoris</i> , <i>L. lactis</i> , subsp. <i>diacetyllactis</i>
Yakult	East Asia	<i>Lactobacillus casei</i>
Yogurt	Worldwide	<i>S. thermophilus</i> and <i>L. bulgaricus</i>

Acidic porridges prepared from cereals are consumed in various regions of the world. Particularly, in Africa, these porridges constitute the basic diet (Table 5). Nigerian *ogi*, Kenyan *uji*, and Ghanaian *kenkey* are examples of porridges prepared by the acid fermentation of maize, sorghum, millet, or cassava, followed by wet milling, wet sieving, and boiling. Mahewu is a traditional sour non-alcoholic maize beverage popular among the Bantu people of South Africa [20], and Hulumur is a Sudanese lactic beverage made from sorghum flour, malt, and spices [21].

Acid fermentation is also used in different regions of the world to produce food starches with extended shelf life, resistance to infectious microorganisms, and palatable flavors. Nigerian *Gari*, Ethiopian *Kocho*, Chinese mung bean starch, and Mexican *pozol* are important acid-fermented starch ingredients used for the preparation of

porridges, steamed cakes, pastes, noodles, soups, and drinks (Table 6) [2, 18].

Gari is a granular starch food made from cassava by fermenting the grated pulp, followed by semi-dextrinizing, drying, and grading. Approximately 10 million tons of Gari are produced per annum in southern Nigeria. Substantial quantities of Gari are produced in coastal regions of West Africa [18].

Most Asian countries produce mung bean starch, and mung bean starch noodles are a staple of the Chinese diet. The mung bean starch manufacturing process involves acidic bacterial fermentation. The mung beans are hydrated by soaking in water inoculated with 12 h steeped water from a previous fermentation to ensure acidification of the beans. The principal microorganisms found in the steep water are *L. mesenteroides*, *Lactobacillus casei*, *L. cellobiosus* and *L. fermentum*. Lactic

Table 4 Acid-leavened bread and pancakes [18]

Product	Country	Principal ingredients	Microorganisms	Usage
Sour bread	Germany	Wheat	Lactic acid bacteria	Sandwich bread
Ryebread, Idli	Denmark, India, Sri Lanka	Rye, Rice, Black gram	Lactic acid bacteria, <i>Leuconostoc mesenteroides</i> , <i>Enterococcus faecalis</i>	Sandwich bread, Steamed cake
Puto	Philippines	Rice	<i>L. mesenteroides</i> and <i>E. faecalis</i>	Steamed cake
Kichudok	Korea	Rice	Yeast	Steamed cake
Enjera	Ethiopia	Tef or other cereals	<i>L. mesenteroides</i> , <i>Pediococcus cerevisiae</i> , <i>L. plantarum</i> , <i>S. cerevisiae</i>	Pancake
Kisra	Sudan	Sorghum, Millet	<i>Lactobacillus</i> sp., <i>Acetobacter</i> sp., <i>S. cerevisiae</i>	Pancake
Kishk	Egypt	Wheat + milk	<i>L. casei</i> , <i>Lactobacillus brevis</i> , <i>L. plantarum</i> , <i>S. cerevisiae</i>	Dried balls
Hopper	Sri Lanka	Rice + coconut water	Yeast, Lactic acid bacteria	Steam-baked, pancake

Table 5 Acid-fermented cereal gruels and non-alcoholic beverages [18]

Product	Country	Primary ingredients	Microorganisms	Usage
Ogi	Nigeria	Maize, sorghum, or millets	<i>L. plantarum</i> , <i>Corynebacterium</i> sp., <i>Acetobacter</i> , and yeast	Sour porridge, baby food, and main meal
Uji	Kenya, Uganda, Tanzania	Maize, sorghum, millets, cassava flour	<i>L. mesenteroides</i> and <i>L. plantarum</i>	Sour porridge, Main meal
Mahewu	South Africa	Maize and wheat flour	<i>L. lactis</i> , <i>Lactobacillus</i> sp.	Sour drink 8–10% DM
Hulumur, Busa	Sudan, Turkey	Red sorghum, Rice and millets	<i>Lactobacillus</i> sp., <i>Lactobacillus</i> sp.	Clear drink

Table 6 Acid-fermented starch ingredients [18]

Product	Country	Principal ingredients	Microorganisms	Usage
Gari	Nigeria	Cassava	<i>Leuconostoc</i> , <i>Alcaligenes</i> , <i>Corynebacterium</i> , and <i>Lactobacillus</i>	Staple Cake Porridge
Mung bean starch	China, Thailand, Korea, Japan	Mung bean	<i>L. mesenteroides</i> , <i>Lactobacillus casei</i> , <i>Lactobacillus cellobiosus</i> , <i>Lactobacillus fermentum</i>	Noodle
Khanom-jeen	Thailand	Rice	<i>Lactobacillus</i> sp. and <i>Streptococcus</i> sp.	Noodle
Pozol	Mexico	Maize	Lactic acid bacteria and <i>Candida</i> sp.	Porridge
Me	Vietnam	Rice	Lactic acid bacteria	Sour food ingredient

fermentation, which reduces the pH to approximately 4.0, protects beans from spoilage and putrefaction that would otherwise occur in ground bean slurries [11].

Khanom Jeen is a Thai rice noodle made from acid-fermented raw rice. Soaked rice is drained and fermented for at least 3 days before grinding, and *Lactobacillus* spp. and *Streptococcus* spp. are involved in acid fermentation.

The microbial composition of Pozol, which is a Mexican starch food ingredient, is quite different from that of Gari and mung bean starches. *Geotrichum candidum*, *Tricosporon cutaneum*, and various *Candida* species are always associated with Pozol in addition to molds such as *Cladosporium cladosporioides*, *Monila sitophila*, and *Mucor ruxianus* [22]. During the first stages of fermentation, the bacteria outnumber the yeast and mold. These bacteria are likely responsible for most of the acid production during the first 24 h. During this period, the pH drops from 7.5 to 5.0 and reaches 3.9 on day 8 of fermentation. During Pozol fermentation, essential changes such as the development of an acidic flavor and characteristic aroma occur in maize dough, conferring Pozol with its refreshing properties when ingested [18].

Acid-fermented vegetables

Consuming vegetable pickles and fermented vegetables is a widespread dietary tradition both in Asia and Europe. The primary retail fermented vegetable products produced in the United States and Europe are cucumber and olive pickles and sauerkraut [23]. Cucumbers were likely first fermented in the Middle East around 2000 BCE. Early written records of cucumber pickles are found in the paper fragment remains of a play (*The Taxiarchs*) by the Greek writer Eupolis (429–412 BCE). Pickles are also mentioned several times in the Christian Bible. European-style sauerkraut is thought to have originated in China and may have been brought to Europe during the Mongol invasion of Central Europe in the thirteenth century.

Acid-fermented vegetables are important sources of vitamins and minerals. *L. mesenteroides* are crucial for the initiation of the fermentation of several vegetables

such as cabbage, beets, turnips, cauliflower, green beans, sliced green tomatoes, cucumbers, olives, and sugar beet silages. In vegetables, *L. mesenteroides* grows more rapidly over a wider range of temperatures and salt concentrations than other lactic acid bacteria. *L. mesenteroides* produces carbon dioxide and acids, which quickly lower the pH, thereby inhibiting the growth of undesirable microorganisms and the activity of their enzymes that may soften the vegetables. The carbon dioxide produced replaces air and provides anaerobic conditions favorable for the stabilization of ascorbic acid and the natural color of vegetables. The growth of this species modifies the environment to favor the growth of other lactic acid bacteria. The high acidic environment created by this species and other subsequent lactic acid bacteria inhibits the growth of *L. mesenteroides*. *L. mesenteroides* converts glucose to approximately 50% levorotatory d-lactic acid, 25% carbon dioxide, and 25% acetic acid and ethyl alcohol. Fructose is partially reduced to mannitol, which is readily fermented to yield equimolar quantities of lactic and acetic acids. The combination of acids and alcohols is conducive to the formation of esters that impart desirable flavors.

Table 7 lists examples of acid-fermented vegetable products in different regions of the world. The difference between sauerkraut and *kimchi* is the preferred end point of fermentation. The best tasting *kimchi* is obtained before the overgrowth of *L. brevis* and *L. plantarum* with an optimal product pH of 4.5. The overgrowth of *L. brevis* and *L. plantarum* diminishes product quality but sauerkraut production depends on these organisms. Vegetable fermentation is also manipulated by salt concentration and temperature. The optimal range of salt concentration in sauerkraut is 0.7, which is approximately 3.0%, whereas that of *kimchi* is 3.0, which is approximately 5.0% [8, 18].

Kimchi is a unique fermented vegetable product with a long history in Korea. *Kimchi* is thought to have originated in the primitive pottery age (8000–3000 BCE) as a result of the natural fermentation of vegetables stored in seawater [8, 24]. To the present day, it remains a main side dish that is served alongside cooked rice and other dishes. In total, 50 types of *kimchi* have been

Table 7 Acid-fermented vegetables produced in different regions of the world [18]

Product	Country	Primary ingredients	Microorganisms	Usage
Sauerkraut	Germany	Cabbage and salt	<i>L. plantarum</i> and <i>L. brevis</i>	Salad, Side dish
Kimchi	Korea	Korean cabbage, radish, various vegetables, and salt	<i>L. mesenteroides</i> , <i>L. brevis</i> , and <i>L. plantarum</i>	Salad, Side dish
Dhamuoi	Vietnam	Cabbage, various, vegetables	<i>L. mesenteroides</i> and <i>L. plantarum</i>	Salad, Side dish
Dakquandong	Thailand	Mustard leaf	<i>L. plantarum</i>	Salad, Side dish
Burong mustala	Philippines	Mustard	<i>L. brevis</i> and <i>P. cerevisiae</i>	Salad, Side dish

identified depending on the use of raw materials, processing methods, and the season and locality of preparation [1]. Kimchi production is the original Korean method of preserving the fresh and crispy texture of vegetables, especially for winter when fresh vegetables are not generally available. *Kimchi* has a unique sour, somewhat sweet, and carbonated taste and is usually served cold. In this respect, *kimchi* differs from sauerkraut, which is acidic in taste and served warm. The raw materials used to prepare *kimchi* are primarily divided into three groups. Korean cabbage and radish are the major ingredients; garlic, red pepper, green onion, ginger, and salt constitute some of the minor ingredients; and fermented fishery products and other seasoning agents are often optional. To prepare kimchi, whole (or cut) cabbage is salted with 15% brine for 3–7 h, washed twice with fresh water, and drained. The minor ingredients are chopped and combined. They are mixed with the treated cabbage, placed in containers, and tightly sealed. The duration of fermentation depends on the salt concentration and temperature. Winter *kimchi* is fermented for 2–3 months to attain optimal taste, whereas summer *kimchi* is fermented for 3–4 days at 20 °C. The optimal pH and acidity for the best taste are 4.2 and 0.6% (lactic acid), respectively [8].

To prepare sauerkraut, the washed and shredded cabbage are stacked in large containers and layered with 2–3% w/w salt. A weight is placed before being covered to force out the liquid from the cabbage. Salt inhibits the growth of many bacterial species, particularly enteric pathogens. Additionally, salt causes the excretion of water from plant cells, creating a brined environment for cabbage leaves. This environment fosters the growth of lactobacilli, which are more halotolerant than many other species, and the lactobacilli ferment

lactic acid. The reduced pH and high salt concentration of sauerkraut significantly extend the shelf life of cabbage. Kimchi and sauerkraut are not usually inoculated with a starter culture, but instead they rely on the natural flora of the fermentation vessels. Owing to the low pH and high salt content of these foods, they are relatively free from microbiological problems if prepared correctly [14].

Acid-fermented fish and meat

The storage life of perishable fish and meat can be extended using acid fermentation via the addition of carbohydrates and salts [25]. In Scandinavian countries, most traditional low-salt-fermented fish products are transformed into pickled vinegar products. These products typically require low-temperature storage. In contrast, most Asian products are lactic acid-fermented with added carbohydrates and salt, as shown in Table 8. Most frequently, rice (either cooked or roasted) is used as the carbohydrate source; however, other sources such as millet in *sikhae* are also used. Rice, millet, flour, syrup, and sugar are also used as carbohydrate sources. In some cases, fruits and vegetables are added; for example, tamarind in *Bekasam* (for the reduction of pH) and garlic and pepper in *sikhae*. Moreover, the antimicrobial effect of garlic on putrefactive microorganisms, such as *Bacillus*, in lactic acid-fermented fish products has been demonstrated [26].

The carbohydrate and salt concentrations primarily control the extent of acid fermentation and maintain the quality. Figure 4 shows the microbial and biochemical changes observed in a typical lactic acid-fermented fish product known as *sikhae*, which is incubated at 20 °C. The pH decreases rapidly from 6.5 to below 5.0 during the first 3–5 days and softening of the texture

Table 8 Acid-fermented seafood and meat products [18]

Product	Country	Major ingredients	Microorganisms	Usage
Sikhae	Korea	Sea water fish, cooked millets, salt, garlic, and red pepper powder	<i>L. mesenteroides</i> and <i>L. plantarum</i>	Side dish
Narezushi	Japan	Sea water fish, cooked millets, and salt	<i>L. mesenteroides</i> and <i>L. plantarum</i>	Side dish
Burong-isda	Philippines	Freshwater fish, rice, and salt	<i>L. brevis</i> and <i>Streptococcus</i> sp.	Side dish
Pla-ra	Thailand	Freshwater fish, salt, and roasted rice	<i>Pediococcus</i> sp.	Side dish
Balao-balao	Philippines	Shrimp, rice, and salt	<i>L. mesenteroides</i> and <i>P. cerevisiae</i>	Condiment
Kungchao	Thailand	Shrimp, salt, sweetened rice	<i>P. cerevisiae</i>	Side dish
Nham	Thailand	Pork, garlic, salt, rice	<i>P. cerevisiae</i> , <i>L. plantarum</i> , and <i>L. brevis</i>	Pork meat in banana leaves
Sai-krok-prieo	Thailand	Pork, rice, garlic, salt	<i>L. plantarum</i> , <i>Lactobacillus salivarius</i> , and <i>Pediococcus pentosaccus</i>	Sausage
Nem-chua	Vietnam	Pork, salt, cooked rice	<i>Pediococcus</i> sp. and <i>Lactobacillus</i> sp.	Sausage

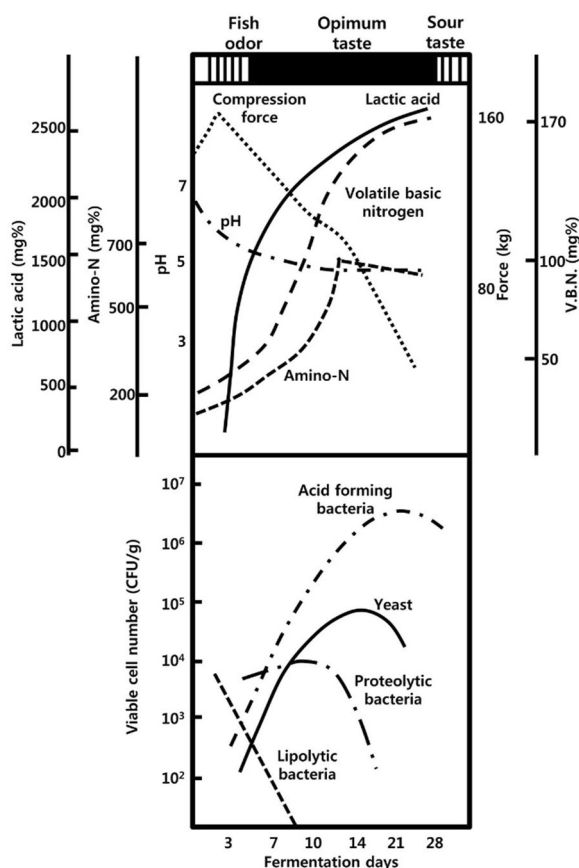


Fig. 4 Microbial and biochemical changes during the fermentation of sikhae [25]

occurs 3–4 days after fermentation. The amino-N concentration increases steadily for up to 14 days, which coincides with the development of the optimum taste. The number of lipolytic bacteria decreases rapidly during the initial stage of fermentation, whereas the number of proteolytic bacteria increases until day 12 of fermentation and thereafter decrease rapidly. The number of acid-forming bacteria increases rapidly making these microbes the dominant microorganisms in the first week of fermentation; their numbers continue to increase and reached a maximum at day 16 of fermentation. Taste deterioration is associated with the maximum growth of yeast and acid-forming bacteria [25].

The bacteria vital for the lactic fermentation have been identified as *L. mesenteroides* and *L. plantarum* [26]. The role of these acid-forming bacteria in the preservation of fish is apparent; however, a more important aspect is their ability to produce an acceptable flavor during fermentation.

Nham is a popular fermented pork food in Thailand. It also consists of fresh trimmed pork meat that is minced and mixed thoroughly with salt, rice, and seasoning. It is traditionally wrapped in small banana leaves. Similar to Western fermented sausages, such as pepperoni and salami, *Pediococcus* sp. (*P. cerevisiae*) is primarily involved in Nham fermentation, although the involvement of *L. plantarum* and *L. brevis* have also been identified [27].

Vinegar

Vinegar is a condiment prepared by sequential alcoholic fermentation and acetification in a process that yields acetic acid as the key ingredient. The acetic acid concentration typically ranges from 4 to 8% (v/v) for table vinegar [28]. Vinegar fermentation is as ancient as alcoholic fermentation because acetic acid is produced during any natural alcoholic fermentation upon exposure to air. Vinegars are produced from fruits in Europe; from tropical fruits such as coconut, sugarcane, and pineapple in the Asia–Pacific region; and from cereals in Northeast Asia.

Cereal vinegar may be classified into three classes: rice vinegar, rice wine filter cake vinegar, and malt vinegar. Indigenous processes are natural or spontaneous fermentations caused by the growth of *Acetobacter aceti* on alcoholic substrates under aerobic conditions. Traditionally, degraded or poor-quality wines are used to produce low-grade vinegars at the household level. Today, vinegars with high-quality standards are produced by at the industry level.

In China, vinegar is primarily produced from grains such as rice, sorghum, wheat, barley, millet, or a combination of these. Chinese vinegar is lighter and slightly sweeter than Western white or cider vinegar, although the former may contain higher acetic acid concentrations [28]. As diverse functions of vinegar have been discovered recently, its use has extended from table seasoning to drinking and health foods. Chinese vinegars, such as Shanxi mature vinegar and Zhenjiang aromatic vinegar are produced via solid-state fermentation. The former is primarily derived from sorghum in a very long maturation process (over 1 year), whereas the latter is primarily prepared from sticky rice. The production of grain vinegar can be divided into four distinct stages: starter culture Qu (*nuruk* in Korean) preparation, saccharification of starch and alcoholic fermentation, acetic acid fermentation, and maturation.

Commercial vinegar is prepared from rice wine filter cakes in far eastern countries. Filter cakes from rice wine factories are collected and packed tightly in a storage tank for 1–2 years. The filter cake contains large amounts of unused carbohydrates and proteins that are

further hydrolyzed by microorganisms and enzymes during storage, converting them into alcohols, other nutrients, and flavored substances. The cake is slurried in 2–3 volumes of water before filtration. The filtrate is heated to 70 °C and cooled to a temperature of 36–38 °C by mixing with fresh vinegar mash. It is then fermented with *Acetobacter* for 1–3 months and further aged at an ambient temperature for 3–6 months. Finally, the fermented product is filtered to obtain clear vinegar [8].

Bread fermentation

Baking, brewing and enology all depend on the ability of yeasts to carry out anaerobic fermentation of sugars, yielding CO₂ and ethanol [2]. In brewing and wine-making, alcohol is the prime product of interest, while in baking the leavening effect of CO₂ is more important. Breads are divided into two groups, leavened loaf bread and unleavened flat bread. Traditionally leavening is due to the products of fermentation, carbon dioxide and ethanol produced by yeast. Although the CO₂ generating chemical leavening agents such as food acid and soda (sodium bicarbonate) can replace yeast, biological leavening imparts physicochemical modification of dough constituents and flavor development.

Originally sour doughs were used to produce all type of breads because commercial baker's yeast was not available. The major microbial species in sourdough fermentations are the lactic acid bacteria (LAB). Fermentation of sourdough by the LAB yields CO₂, which raises the bread its distinctive tangy flavor. Baker's yeast was introduced in the market at the beginning of the twentieth century. Industrially produced yeasts are strains of the top-fermenting species *S. cerevisiae* grown on molasses in an aerobic fed-batch fermentation. The optimum temperature for the growth and fermentation of baker's yeast is between 28 and 32 °C, and the optimum pH is 4–5. Leavening of dough requires the addition of 1–6% yeast based on the weight of flour. The exact percentage depends on the recipe, the process and the quality of the flour and yeast as well as the operation conditions [2].

Amino acid/peptide-fermented foods

Fermented protein foods are primarily used as flavor-enhancing condiments and gourmet food ingredients because of the meaty and appetite-stimulating flavor of the protein hydrolysate that is formed during fermentation. The type of fermented protein food that is indigenous to a region primarily depends on the availability of raw materials under the specific climatic and geographical conditions. Cheese is produced in the Middle East and Europe, where animals are the main food sources. Fermented soybean products, such as soybean sauce and paste, are used

in Northeast Asian countries, and fermented fish products are used in the Asia–Pacific region [2].

Cheese

The number of cheese varieties worldwide is estimated to be 500, and several methods are used to classify cheese. For instance, they can be classified according to their texture into very hard (Parmesan, Romano), hard (Cheddar, Switzerland), semi-soft (Brick, Muenster, blue, Harvarti), soft (Brie, Camembert, feta), and acidic (cottage, cream, Ricotta) cheese. Another broad classification divides cheeses into two categories: ripened and fresh. More technical classifications are also used, such as those based on coagulating agents, including rennet cheese (Cheddar, Brick, Muenster), acid cheese (cottage, quarg, cream), heat-acid cheese (Ricotta, Sapsago), and concentration-crystallization cheese (Mysost) [29].

Cheese is manufactured by coagulating or curdling milk, stirring and heating the curd, draining the whey, and collecting or pressing the curd. Characteristic flavors and textures are formed during cheese ripening, depending on the type of starter culture, microorganisms involved, coagulating agent, and salting methods. Depending on the variety, the milk is pasteurized (generally at approximately 72 °C for 16 s), and a bacterial starter culture is added to the milk, at 30–36 °C. The inoculated milk is generally ripened at a temperature of 30–60 min to allow lactic acid bacteria to multiply sufficiently for their enzyme system to convert lactose to lactic acid. After ripening, a milk-coagulating agent is added. For blue cheese, a mold (*Penicillium* sp.) is added to the starting milk or drained curds.

Starter cultures are organisms that ferment lactose to lactic acid and other products. These include *Streptococci*, *Leuconostoc*, *Lactobacilli*, and *Streptococcus thermophilus*. Starter cultures also include *Propionibacteria*, *Brevibacterium*, and mold species of *Penicillium*. The latter organisms are used in conjunction with lactic acid bacteria for a particular characteristic of cheese; for example, the holes in Swiss cheese are attributed to *Propionibacteria*, and the yellowish color and typical flavor of brick cheese are attributed to *Brevibacterium linens*.

Milk coagulation is essential for cheese production. Most proteolytic enzymes cause milk coagulation. Rennet (chymosin; EC 3.4.23.4) is widely used to coagulate milk during cheese production. However, owing to the shortage of calf chymosin, commercial rennet may include blends of chymosin and pepsin extracted from the stomachs of other animals such as pigs. Microbial rennets with similar functionalities have been prepared from *Mucor miehei*, *Mucor pusillus*, and *Endothia parasiticus*. Proteases from plants are known to coagulate milk but are not used in commercial cheese production [2].

Fish sauce and paste

Fish fermentation is an old technology used for the preservation of freshwater and marine animals that are highly perishable, localized in production, and seasonally fluctuating in catch [30]. This technology appears to have evolved with the availability of salt and a non-pastoral way of life. The consumption of fermented fish products has strongly correlate worldwide with the use of cereals, especially rice and vegetables [31]. Although the use of fermented fish products is currently confined to East and Southeast Asia, traces of this technology can be found at all time periods of the older human civilizations.

Aging salted (cured) fish in a container or earthen jar for a long period produces fish sauce. Enzymes in the gut and from halophilic microorganisms grown in the system decompose fish meat, and the exuded liquid (protein hydrolysate) is collected as fish sauce. The hydrolysate mainly consists of amino acids and peptides, which form the characteristic meaty flavor of fish sauce. The Korean *Jeotkal* fermentation contains 20% salt, and the total number of viable cells increases during the first 40 days, which is mainly attributed to the growth of *Pediococcus* and *Halobacterium*. The concentrations of soluble N and amino N increases steadily during the first 60 days and coincides with the development of the optimum taste. The volatile basic N content increases in two steps, and the second step, which is related to the maximum growth of yeast, causes taste deterioration [32].

Depending on the amount of salt added, the products are classified as high-salt (>20% salt of the total weight), low-salt (6–18% salt), and no-salt products. When the salt concentration is higher than 20% of the total weight, pathogenic and putrefactive microorganisms cannot grow, and the product does not require other means of preservative. The first criterion for the subdivision of this group is the degree of hydrolysis, which is influenced by fermentation time, temperature, added enzyme sources, and water content. The fully hydrolyzed liquid is fish sauce. The cured fish is the partially hydrolyzed fish product that retains the original shape of the fish immersed in the exuded liquid, and fish in this form is frequently used as a side dish for rice meals. Fish paste is characterized by the partial drying of salted fish to restrict the degree of hydrolysis and grinding it to produce a homogeneous solid condiment. Each class can be further subdivided by the type of raw material used, such as fish species and portion of fish; thus, this fermentation method yields numerous types of products [25].

Many Asian countries produce salt-cured and dried fish products, such as *plakem* in Thailand, *jambalroti* in Indonesia, Maldive fish in Sri Lanka, and *gulbi* in Korea; however, the role of fermentation in these products is

not fully understood. Fish fermentation without salt addition is not a common practice. However, preparing half-spoiled fish or performing alkaline fermentation in leafy plant ash in a local specialty in some regions. The propagation of mold during dried bonito (*katsuobushi*) processing in Japan is another example of non-salt fish fermentation.

Most countries in East and Southeast Asia have fish sauce; however, the flavor, physical properties, and raw materials used vary. Depending on the degree of hydrolysis, fermentation time, and separation method, sauces may be classified into two types, namely clear, and turbid. *Ngan-pya-ye*, *nuoc-man*, *nampla*, *shottsuru*, and *yu-lu* are clear fish sauces, whereas *budu*, *patis*, *ketjapikan*, and *jeot-kuk* are turbid. Some turbid sauces exude liquids of cured fish; for example, *patis* from *bagoong* production in the Philippines and *jeotkuk* from *jeotkal* production in Korea. Cured fish products are preferred over fish paste products in Northeast Asia. Fish pastes, especially those made from shrimp and planktonic animals such as *Sein-sangapy*, *belacan*, *trassi*, *prahoc*, and *kapi*, are important in Southeast Asian diets [2].

Fermented soybean products

The manufacturing of fermented sauces using soybean is estimated to have begun in Korea and the Southern Manchuria in the 1000 s BCE by the people Dong-yi (Eastern Archers), who initiated the use of soybean as food. The people lived in the Southern Manchuria and Korean Peninsula, Han, Ye and Maek tribes, were called by Chinese as Dong-yi, which meant the people carrying a bow and arrow in the east. This inference is supported by written records that state that soybeans, which were introduced to China in the seventh century BCE from South Manchuria, were handily converted into soybean-fermented food (*Si*; *Chi* in Chinese) by the time of the Han dynasty in 220 BCE. According to Huang [33], *Chi* is not mentioned in Chinese literature until the Qin dynasty (221–209 BCE). Zhang Hua's *Bówùzhì* (Records of diverse matters, 290 CE) states that "There is *Chi* in other countries." *Běncǎo Gāngmù* (Compendium of *Materia Medica*) by Li Shizhen (1518–1593) also mentions *Chi* as a foreign product. A passage in *Xuèzhāi Zhānbǐ* (a Northern Song (960–1126 CE) book of textual criticism) reads, "The word '*Chi*' does not appear in the *Jiūjīng* (Nine classics); only a dialect of the word appears." In an article on Goguryeo found in *Sānguózhì* (Record of the Three Kingdoms), Book of Wei, Biography of the Dong-yi (8–265 CE), the people of Goguryeo (37 BCE–668 CE) are described as excelling in fermentation techniques. Additionally, a quotation from *Xīn Táng Shū* (New Book of Tang) in *Haedong Yeoksa* (A History of Korea), which was compiled during the time of Kings Jeongjo

(r. 1776–1800) and Sunjo (r. 1800–1834) of the Joseon dynasty, states that the emissaries were carrying *Si* from the capital Bohai (Kor. Balhae, 698–1116 CE), which was a country established by Goguryo refugees, and it was a specialty food of that region [34].

In the early stage of soybean utilization, Northeastern Dong-yi people probably first invented *Si* (the old Chinese term for Korean *meju*) by storing cooked soybeans in a straw mat or pottery jar. Cooked soybeans grown with mold and bacteria (referred *meju*) are immersed in brine to leach the protein hydrolysate; the liquid part is soybean sauce (*kanjang*), and the residue is soybean paste (*doenjang*).

Traditional fermented soybean products are classified into three groups based on the type of fermentation starter used: *Si* made from loose-type cooked whole soybean, *Maljang* from cake-type soybean *meju* and *Jang* from soybean mixed with other cereals. The propagation of these products in the northeastern region, namely China, Korea, and Japan, and their variations are shown in Fig. 5 [28, 35]. According to Lee [36], fermented soybean products were first introduced in China in the first century BCE and in Japan in the seventh century CE. Various products have been developed and have disappeared throughout history. Soybeans are generally thought to have spread throughout southeastern China

and Southeast Asia by 700 CE owing to immigration from China. Soybean fermentation technology was probably transferred to this region in tandem with Chinese immigrants [34].

Soybean sauce and paste

Although Soybean sauce is popularly considered a vital and indispensable seasoning in Asian cuisine, different cultures and regions have different taste preferences and manufacturing processes. Soybean sauce processes can be divided into two types—those that use pure cultured *koji* made from soybeans (or defatted soybean flakes) with added starch cereals (rice, wheat, barley, etc.) (Chinese *jangyou* and Japanese *shoyu*), and those that use natural fermentation starters (*meju*) made from soybeans only (Korean *ganjang*, Japanese *tamari-shoyu*, and Indonesian *kecap*).

Soybean paste is the generic name for the semi-solid/solid form of condiments made from fermented soybean. Some examples are Chinese *doujiang*, Korean *doenjang* and *kochujang*, Japanese *miso*, and Indonesian *taoco*, (which are distinguished according to the starter culture used (*koji* or *meju*) and the use of added starch ingredients). According to their flavor, Chinese soybean sauces, *jangyou*, are classified as light/fresh (*shengchou*) or dark/old (*laochou*) soybean sauce [28].

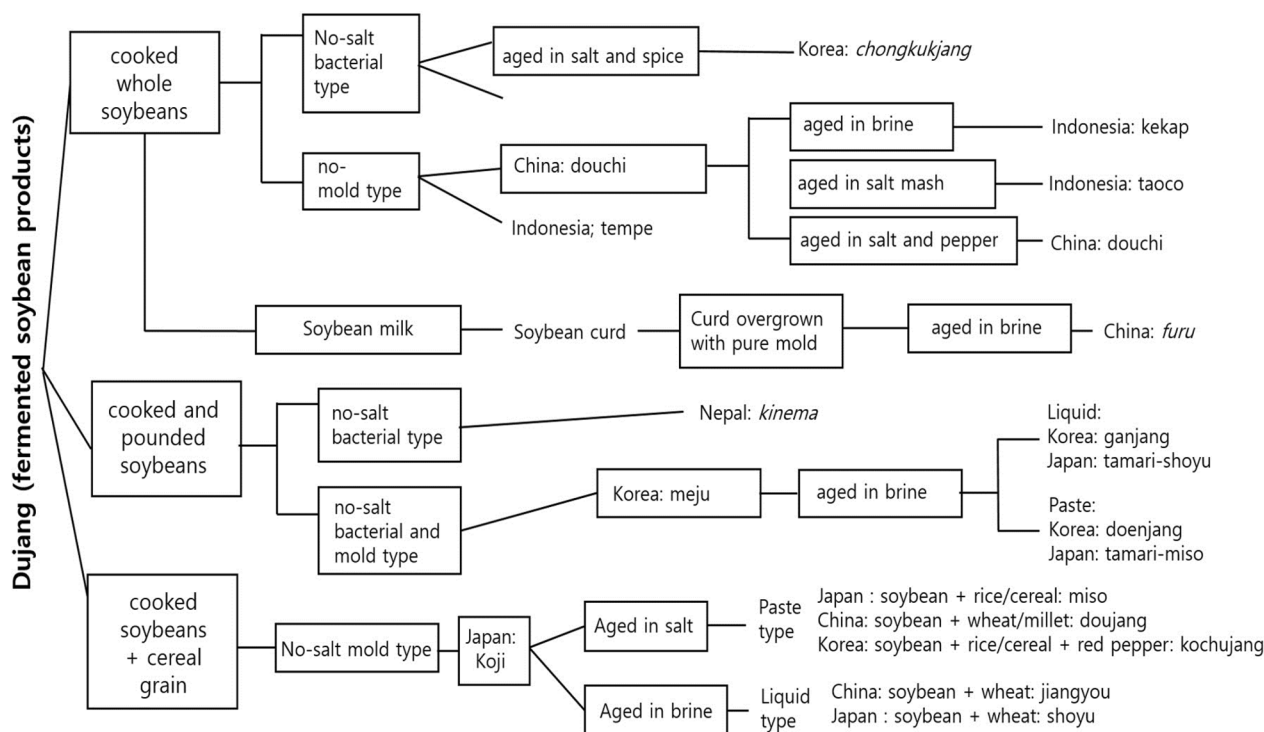


Fig. 5 Origin and interchange of fermented soybean products in East Asia [28]

Korean *kanjang* and *doenjang*

Meju is prepared using cooked soybeans. Soybeans are soaked in water overnight, cooked for 2–3 h and mashed by pounding. The mash is shaped like a brick or ball, dried in the sun, and kept in a covered stack during the night for several days. During this period, mold (particularly, *Aspergillus oryzae*) grows on the surface, and bacteria (typically *Bacillus subtilis*) grows on the inside. Enzymes from the mold and bacteria hydrolyze the soybean proteins into amino acids and the carbohydrates into sugars and organic acids. Amino acids and sugars interact with each other during the browning reaction, resulting in a characteristic dark brown color and a meaty flavor. Properly fermented *meju* is immersed in brine in an earthen jar and ripened for several months. The brown color and meaty flavors leach into the brine. During this period, salt-tolerant yeasts (particularly *Saccharomyces rouxii*) grow in the mash, and it produces the soy sauce aroma. In the final product, the liquid component is the soy sauce, and the precipitate is the soybean paste. Soy sauce is boiled once and stored in an earthen jar for several years, and it develops a richer flavor as the storage time increases (just as wine develops a smoother flavor as it ages) [8]. An old saying asserts that in Korea, the taste of food in a household is determined by the taste of their fermented soybean product.

Japanese *shoyu* and *miso*

The Japanese people modified the *meju* preparation method in the early twentieth century by controlled fermentation technology using a pure culture of mold isolated from a traditional starter [37]. Molds (typically, *Aspergillus oryzae*) are grown on cooked rice or cooked wheat grit to make *koji*, which is then mixed with cooked soybeans for further fermentation and ripened in brine. Soybean paste (*miso*) and soy sauce (*shoyu*) are made separately; for *shoyu*, *koji* is made from cooked defatted soybean flakes and wheat grit and mixed in brine for aging for 4–6 months. The mixture is filtered to obtain *shoyu*, and the liquid and solid parts are discarded. *Miso* is prepared using *koji* made from cooked rice or other cereals mixed with cooked soybeans and salt, which is mashed into a paste and ripened. These processes lend themselves to easy industrialization for product production. The flavors of Japanese *shoyu* and *miso* are milder and sweeter than those of their Korean counterparts. Koreans prefer the strong flavor of traditional soy sauce and soybean paste, similar to the preference among Europeans for Roquefort over processed cheddar cheese.

Korean *kochujang*

European taste profiles are basically inclined toward sweet, sour, bitter, and salty, whereas the Japanese prefer to include umami or the meaty taste. In contrast, Koreans prefer to also include hot or pungent tastes. The most remarkable difference between the foods from Korea and those of their neighboring countries, such as Japan and China, is the strong pungent taste of red pepper in most Korean dishes.

Kochujang is a unique hot bean paste seasoning that is popular in Korea. It is made from a fermented soybean starter, *meju*, and malt made from barley. Malt powder was mixed with a cereal porridge prepared from rice, glutinous rice, or barley. The enzymes in malt hydrolyze the starch into sugars and reduce the consistency of the mixture. *Meju* powder, red pepper powder, and salt are added to a partly saccharified porridge with thorough mixing to make a paste, which is then placed in an earthen jar. The top is covered with salt to prevent the growth of mold. The jar is placed in a sunny environment for further fermentation. The proteins in soybeans and cereals degrade into amino acids to produce a meaty flavor. During fermentation, the meaty flavor of hydrolyzed proteins, the sweet taste of hydrolyzed starches, the pungent taste of red pepper, and salty taste harmonize well, and a new characteristic flavor that stimulates the appetite of Koreans is formed [2].

Non-salt-fermented soybean foods

Non-salt-fermented soybean foods include *natto* (Japan), *chongkukjang* (Korea), *douchi* (China), *kinema* (Nepal), *pepok* (Myanmar), *thua nao* (Thailand), *sieng* (Cambodia), produced using *Bacillus subtilis*, and *tempe* (Indonesia, produced using *Rhizopus oligosporus*). Nakao [38] proposed the idea of the Natto Triangle, with three apexes set in Japan (*natto*), Nepal (*Kinema*), and Indonesia (*tempeh*). The center of the triangle is in the Yunnan province of China; he speculated that Yunnan was the origin of *natto*- or non-salt-fermented soybeans. Tamang [39] proposed the *kinema-natto-thua nao* (KNT) triangle based only on the locations producing non-salt-fermented soybeans using *Bacillus subtilis*, as shown in Fig. 6 [40]. However, these ideas have limitations because they are lacking in the knowledge that the old history of soybean fermentation states that it originated from South Manchuria and the Korean Peninsula. The origin of both non-salt and salted soybean fermentation appears to be northeastern China and the Korean Peninsula, as discussed above. Many non-salt-fermented soybeans, such as *chongkukjang* in Korea, are mixed with salt at the

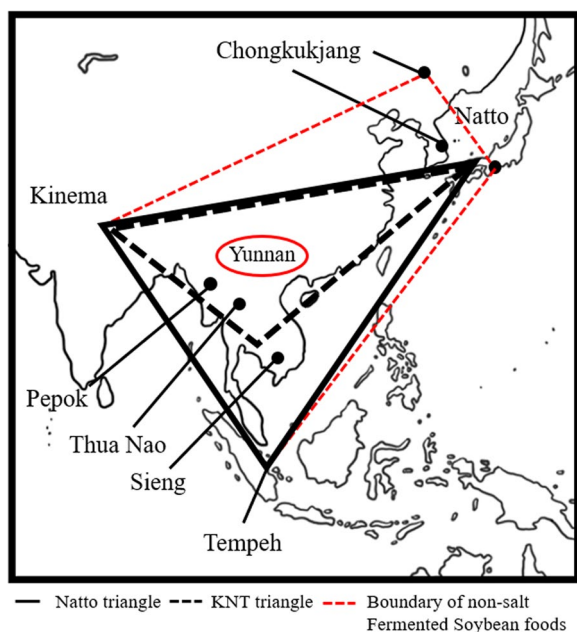


Fig. 6 Geographic boundary of non-salt-fermented soybean foods [40]

final stage of use and storage (for example, *chongkukjang* in Korea). The geographic boundaries of non-salt-fermented soybean foods are shown in Fig. 6.

Korean *chongkukjang* and Japanese *natto*

Chongkukjang is processed as follows. Soybean is cooked and covered with a straw mat or cloth and placed on the *ondol* (which is the warm stone floor) at approximately 40 °C for 3–4 days until the mucous string is formed. *Bacillus subtilis* is the dominant microorganism, and it produces strong proteolytic enzymes. The product is mixed with chopped ginger, chopped garlic, and salt, pounded slightly until the bean kernels separated into halves, and stored in an earthen jar. The strong smell of fermented soybeans due to the production of ammonia is partially masked by the smell of ginger and garlic. This creates the characteristic *chongkukjang* flavor. This spicy seasoning is prepared in 3–4 days, unlike that of ordinary soybean paste, *doenjang*, which uses *meju* as a fermentation starter and requires over 6 months for complete ripening. In this respect, *chongkukjang* is a rapidly fermented soybean sauce. The mucous substance in *chongkukjang* is a peptido-polysaccharide produced by *Bacillus subtilis* [41].

Natto is a fermented soybean grown with *Bacillus subtilis* on cooked soybeans and is mainly produced and consumed in Japan. Fermented soybean with mucous strings is consumed directly without further processing; therefore, it is a typical non-salt-fermented product.

However, other types of *natto* are also produced in Japan; the salted types include *shiokara-natto*, *tera-natto*, and *hama-natto*, which are similar to *chongkukjang* and ordinary soybean sauce. A variety of processed *natto* are also produced including *hoshi-natto* (dried *natto*), *soboro-natto* (mixed with sliced dried radish), and *goto-natto* (fermented with *Aspergillus* or *koji* mold in the presence of salt) [40]. *Natto* is consumed raw in Japan and is highly popular; however, it is not generally preferred in Korea.

Kinema

Kinema is a unique flavorsome delicacy consumed by the people of Nepal and their neighbors. Indigenous soybean-fermented condiments are low-cost meat substitutes and a source of income for many rural households [42]. Small-sized soybeans of the yellow cultivar are washed and soaked in water at an ambient temperature. The soaked beans are drained, cooked by boiling for 2–3 h, and lightly crushed using a wooden pestle and mortar. According to the established indigenous practice, the mortar and pestle is not cleaned before crushing another batch. The grits are transferred to a bamboo basket lined with sackcloth and a layer of locally available fresh fern fronds or banana leaves. At this stage, the beans are still hot (50–60 °C). To obtain an alkaline environment, small amounts of firewood ash are often sprinkled over the grits before being wrapped in the leaves and sackcloth for insulation. The fermenting beans are then placed in a warm room (35–25 °C) for 1–3 days. The desired state of fermentation is determined primarily by a typical kinema flavor that is dominated by ammonia and the development of a rough white viscous fluid on the beans. Good-quality fresh kinema presents a nutty flavor accompanied by a mild smell of ammonia and a grayish brown color. They are semi-hard like raisins. Frying fresh kinema in oil releases a pungent smell of ammonia for a few seconds before disappearing and leaving behind a persistent nutty odor. After brief frying, the kinema is mixed with vegetables (grated onion, tomatoes, and green pepper), spices, salt, and a small amount of water and cooked for 5 min to form a thick curry, which is eaten as a side dish of steamed rice. Fresh kinema keeps well for 2–3 days during the summer and for a week during the winter. The shelf life is often extended to several months by drying the kinema in the sun or by storing it above an earthen oven in the kitchen [43].

Tempe

Tempe is found in all parts of Indonesia but is a staple particularly in Java and Bali. It is also produced in some Malaysian and Singaporean villages. *Tempe* is a white mold-covered cake produced by fungal fermentation of

dehulled, water-soaked, and partially cooked soybean cotyledons [11]. It is packed in wilted banana leaves and sold on the market. The essential steps in the preparation of *Tempe* include cleaning the beans, soaking them in water, dehulling, and partial cooking of the dehulled beans. Dehulling is important for the growth of molds on the surface of the cotyledons. Soybeans are not necessarily cooked fully because the subsequent mold growth would further soften its texture. Under natural tropical conditions, *tempe* production involves two distinct fermentation processes: bacterial acidification of beans during soaking and fungal overgrowth of the mold mycelia in the cooked bean cotyledons. A previous batch of sporulated *tempe* or sun-dried pulverized *tempe* powder (1–3 g) is sprinkled over the cooked and drained soybean cotyledons (1 kg) and thoroughly mixed to distribute the mold spores over the surface of all beans. *Rhizopus oligosporus* is known as *tempe* mold, and pure cultures of strains NRRL2710 or CBS 338.62 can be used as the inoculum.

A handful of the inoculated beans are placed on wilted banana leaves or other large leaves and packed. The leaves keep the soybean cotyledons moist during fermentation and allow gaseous exchange. Incubation occurs at temperatures ranging from 25 to 37 °C. The higher the incubation temperature, the faster the growth of the *tempe* mold. For example, 80 hours of incubation is required at 25 °C, 26 h at 28 °C, and 22 h at 37 °C. The *Tempe* is harvested when the bean cotyledons are completely overgrown and knitted into a compact cake. At this stage, the cotyledons are soft and pasty (not rubbery) and the pH has increased to approximately 6.5.

Tempe needs to be consumed immediately after harvesting. It can be stored for 1–2 days without refrigeration. However, *Tempe* that is not consumed immediately is either deep-fried to retain its stability for a considerable time or blanched by steaming and refrigerated. Additionally, it is dehydrated either by sun drying or hot air drying and stored in plastic bags. If these steps are followed the quality of *Tempe* during stored is maintained quite well as it contains a strong antioxidant that is produced by the mold and is hence resistant to the development of rancidity. *Tempe* is consumed fresh or deep-fried.

Chinese Sufu

Chinese *Sufu* (*tosufu*, *toufuru*, *fuyu*, or *tauhuyi*) is a highly flavored creamy bean paste made by overgrowing soybean curd with a mold belonging to the genera *Actinomyces*, *Rhizopus*, or *Mucor* and fermenting the curd in a salt brine/rice wine mixture [44]. In the West, *Sufu* is referred to as Chinese cheese. *Sufu* is usually sold as red or white blocks that are 2–4 cm² and 1–2 cm thick. White *Sufu* is untreated, whereas the red variety is

colored with Chinese red rice and *hung chu*. The procedure for preparing *Sufu* consists of five steps: preparation of soybean curd (tofu), preparation of molded *tofu* (*pehtze*), salting, fermentation in salt brine/rice wine, processing, and packaging.

Soybeans are cleaned, soaked in water, and ground to obtain soybean milk slurry. The slurry is heated to boiling temperature and filtered through a cloth; the residue is discarded. Coagulants (a calcium chloride/calcium sulfate mixture or sea salt brine) are added to the filtered soymilk to prepare soybean curd. The quantity of coagulant used to produce *tofu* for *sufu* manufacture is 20% higher than that used for regular *tofu*. After the coagulates are mixed with soybean milk, the mixture is agitated vigorously to break the coagulated proteins into small pieces. It is then set aside for 10 min to complete the coagulation process. This process reduces the water content of the curd and makes texturing more difficult. If the water content is >60%, fungal inoculation is deferred until the quantity of water remaining on the curd surface is reduced by drying.

Pehtze is a soybean curd overgrown with grayish hair-like mycelia of molds belonging to the genera *Actinomyces*, *Rhizopus*, or *Mucor*. These fungi are typical rice straw contaminants. Traditionally, inoculation is performed by placing *tofu* on rice straw; however, this method does not always yield a high-quality product because of undesirable contaminating microorganisms. In spring and autumn, when the ambient temperature is 10–20 °C, white fungal mycelia are visible on the surface of the cubes after 3–7 days. The cubes are removed at this stage and salted immediately in large earthenware jars. Each layer of *pehtze* is sprinkled with a layer of salt. After 3–4 days, the salt is absorbed, and the *pehtze* is removed, washed with water, and placed in another jar for processing.

Processing is performed using a dressing mixture, which varies depending on the type of *Sufu* placed in the jar. *Anka koji* and soy mash are added to make red *Sufu*; fermented rice mash is added to make fermented rice (*tsao*) *Sufu*; and red pepper and anise are added in addition to salt and red *koji* to make Kwantung *sufu*. Alternate layers of *pehtze* and dressing mixture are packed into the jar until it is filled to 80% of its volume. Then, a brine (approximately 20% NaCl) is added. Finally, the mouth of the jar is wrapped with leaf sheaths of bamboo shoots and sealed with clay for 3–6 months of fermentation and aging, after which the *Sufu* is ready for consumption [11].

Other fermented products

Chinese red rice (Anka)

Anka is also known as *ang-kak*, *beni-koji*, or red rice. It is used in China, Taiwan, the Philippines, Thailand, and

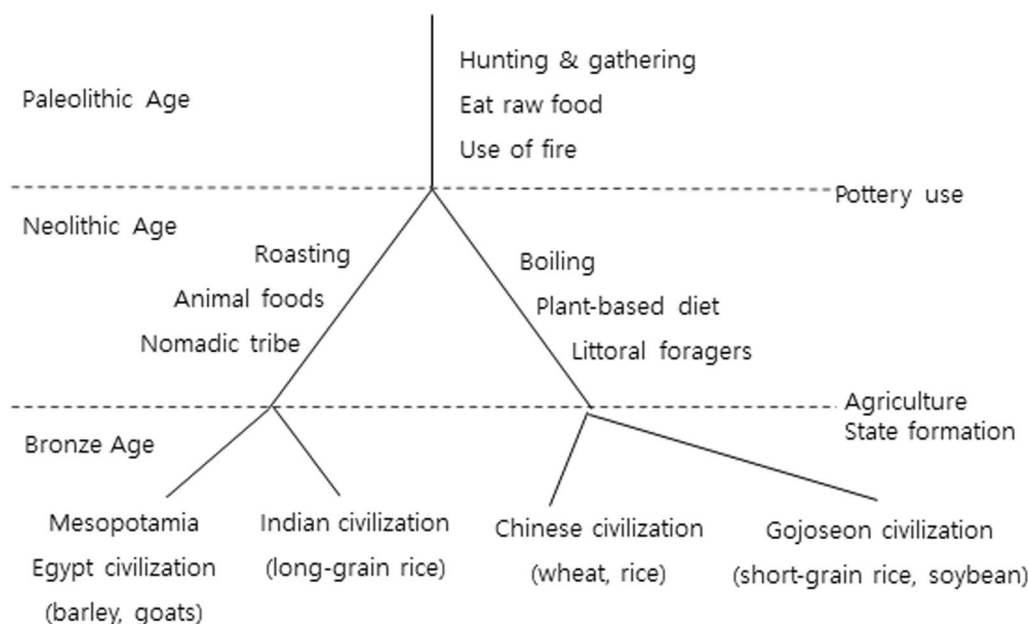


Fig. 7 Genealogy of the development of world food culture [46]

Indonesia to color foods such as fish, rice wine, red soybean cheese, pickled vegetables, and salted meats [44]. It is the product of rice fermentation by various strains of *Monascus purpureus* Went. Several countries are gradually adopting this natural pigment to replace coal tar dyes, as the latter has been implicated as a carcinogen. The advantages of using *Anka* are that its raw materials are readily available, the yield is high, the color of the pigment produced is consistent and stable, the pigment is water-soluble, and it has not exhibited evidence of any toxicity or carcinogenicity.

Anka is produced on an industrial scale in Taiwan. Non-glutinous rice (1450 kg) is washed and steamed for 60 min. Water (1.8 hL) is sprayed onto the rice, which is steamed again for 30 min. The steamed rice is mixed with 32 L of *chu chong tsaw*, which is a special variety of red rice inoculum in Taiwan. After cooling to 36 °C, it is heaped in a bamboo chamber. At 42 °C, it is spread on plates and shelved. *Anka* is produced by moistening the rice thrice during incubation, followed by a final drying; thus, 700 kg of *Anka* is produced from 1450 kg of rice.

The mold *Monascus purpureus* exhibits an uncommon phenomenon of exuding granular fluid through the tips of the hyphae. When the culture is still young, the freshly extruded fluid is colorless but it gradually changes to reddish-yellow and purple-red color on aging. Additionally, the production of red-colored matter is observed in the hyphal content within, and the red coloring matter

diffuses throughout the substrate. The dark red color consists of two pigments: red monascorubrin (C₂₂H₂₄O₅) and yellow monascoflavin (C₁₇H₂₂O₄). The strains of *Monascus purpureus* used for the production of red rice are only organisms capable of imparting the dark red color to rice at water concentrations that sufficiently low to not distort the hydrated grains [2].

Korean Hongoehoe

Hongoehoe is a fermented raw skate that is traditionally eaten in the southern area of South Korea [41, 45]. A few documents from the late Koryo Dynasty (fourteenth century) in Korea recorded that the residents of *Heuksando*, which is an island located far away from the southeastern coast of Korea, moved to the mainland due to frequent foreign invasions. However, they continued fishing near *Heuksando*. Owing to the island’s distance from the mainland, the skates (*hongoe*) fermented on board during the several days that it took them to sail back home. They learned that eating fermented *hongoe* did not harm their stomachs even in hot summers and that its taste was better than that of fresh *hongoe*.

Hongoehoe is prepared by cleaning the skate with paper after degutting the viscera. It is then placed in a straw bag during in the summer or in the compost during the winter. Refrigerators or low-temperature chambers are currently used in the fermentation process for safety control and constant quality. Hongoehoe has a strong



Fig. 8 Division of seasoned food culture in East Asia [35]

ammoniacal odor. The unique taste and odor of hongeo-hoe originate from nitrogenous compounds, such as ammonia, urea, and trimethylamine, which are essential for osmoregulation in the deep sea. The ammonium concentration in fermented skates collected from the Korean market ranges from 4.4 to 14.1 mg/g. The pH value is initially < 7.0 but increases to 9.4 after fermentation, which indicates a typical alkaline fermentation. Hongeo-hoe is usually served uncooked with other side dishes such as kimchi and pork dishes.

Conclusion

Food technology has evolved throughout human history. The use of fire during the Paleolithic Age has initiated human foodways by encouraging the use of roasting and drying techniques in food consumption. The primitive pottery culture of Northeast Asia (8000–3000 BCE) in the early Neolithic Age has ushered in an era of boiling and fermentation technology. With the invention of earthenware vessels, people were able to set aside water for boiling and cooking. The maintenance of wet food in

these vessels resulted in spoilage or natural fermentation. The foodways of people gradually changed from carnivorous to omnivorous because of the use of pottery.

The use of primitive pottery by Northeast Asians was a watershed development that divided the human food culture into roasting and boiling cultures. The roasting culture of Westerners, which descended from nomadic people, developed into a meat-oriented food culture. In contrast, East Asians who used pottery developed a vegetarian culture premised on soaking hard grains, plant tissues, and roots in water for boiling (Fig. 7) [46].

Soybean culture emerged in ca. 2000 BCE in South Manchuria and the Korean Peninsula. The Dongyi people are thought to be the first users of soybeans as food, which they developed by applying boiling technology to remove trypsin inhibitors from raw soybeans. Soybean fermentation began quite soon after soybean food use through the adoption of cereal alcoholic fermentation technology. Cultivated soybeans were transferred to China from Manchuria in the seventh century BCE and spread further to Southeast Asia from the fourth to seventh centuries CE. East Asia can be divided into soybean sauce and fish sauce cultures, as shown in Fig. 8 [35]. This demonstrates the significant influence of Korean fermentation techniques on the formation of East Asian food cultures.

Meaty-flavor production by fermentation is an important food technology in East Asia. Gut enzymes and microorganisms in fish are used to break down proteins into savory peptides and amino acids. In soybean fermentation, mold (*Aspergillus oryzae*) and bacteria (*Bacillus subtilis*) are grown selectively on cooked soybeans to break down proteins and produce meaty flavors. The protein conversion rate of doenjang is estimated to be approximately 80%, whereas that of beef is only 5% [8].

Food science and technology have been developed to expand food availability, enhance food nutrition and safety, and improve convenience and marketability. Future food research should focus on the economic use of food materials, enhancing the palatability of vegetable foods, and reducing food loss and waste. Fermented ethnic foods are valuable resources for the development of novel foods such as meat analogs and protein food substitutes. The demand for functional customized foods will accelerate the production of fabricated and designed foods. Hence, old wisdom regarding traditional foods could provide clues for solving future global food problems. Finally, harmony and collaboration are required between Eastern and Western food systems for a positive paradigm shift in food science and technology.

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Author contributions

Cherl-Ho Lee was involved in the conceptualization, methodology, formal analysis, visualization, writing—original draft, and writing—review and editing. Junyoung Ahn contributed to writing—review and editing and visualization. Hong-Seok Son participated in the conceptualization, writing—original draft, writing—review and editing, and supervision.

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Availability of data and materials

The data supporting the findings of this study are available from the corresponding authors upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All the authors have read and approved the content of this manuscript for a publication.

Competing interests

The authors declared no competing interests.

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