fermentation

Review

Fermented Foods of Korea and Their Functionalities

Su-Jin Jung [1,2,†], Soo-Wan Chae [1,2] and Dong-Hwa Shin [3,4,*,†]

[1] Clinical Trial Center for Functional Foods, Biomedical Research Institute, Jeonbuk National University Hospital, Jeonju 54907, Republic of Korea
[2] Research Institute of Clinical Medicine, Medical School, Jeonbuk National University, Jeonju 54907, Republic of Korea
[3] Shin Dong Hwa Food Research Institute, Seoul 06179, Republic of Korea
[4] Department of Food Science and Technology, Jeonbuk National University, Jeonju 54896, Republic of Korea
* Correspondence: dhshin@jbnu.ac.kr; Tel.: +82-10-5280-2570; Fax: +82-63-259-3060
† These authors contributed equally to this work.

Abstract: Fermented foods are loved and enjoyed worldwide and are part of a tradition in several regions of the world. Koreans have traditionally had a healthy diet since people in this region have followed a fermented-foods diet for at least 5000 years. Fermented-product footprints are evolving beyond boundaries and taking the lead in the world of food. Fermented foods, such as jang (fermented soybean products), kimchi (fermented vegetables), jeotgal (fermented fish), and vinegar (liquor with grain and fruit fermentation), are prominent fermented foods in the Korean culture. These four major fermented foods have been passed down through the generations and define Korean cuisine. However, scientific advancements in the fermentation process have increased productivity rates and facilitated global exports. Recently, Korean kimchi and jang have garnered significant attention due to their nutritional and health-beneficial properties. The health benefits of various Korean fermented foods have been consistently supported by both preclinical and clinical research. Korean fermented foods effectively reduce the risk of cardiovascular and chronic metabolic diseases, such as immune regulation, memory improvement, obesity, diabetes, and high blood pressure. Additionally, kimchi is known to prevent and improve multiple metabolic diseases, including irritable bowel syndrome (IBS), and improve beneficial intestinal bacteria. These functional health benefits may reflect the synergistic effect between raw materials and various physiologically active substances produced during fermentation. Thus, fermented foods all over the world not only enrich our dining table with taste, aroma, and nutrition, but also the microorganisms involved in fermentation and metabolites of various fermentations have a profound effect on human health. This article describes the production and physiological functions of Korean fermented foods, which are anticipated to play a significant role in the wellness of the world's population in the coming decades.

Keywords: fermented food; kimchi; jang; jeotgal; vinegar; health functions

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1. Introduction

Fermentation was first scientifically defined 500 years ago [1,2], yet humans have used fermented foods for ages. In the early days, humans used natural products and relied on natural phenomena for fermentation. For instance, fermentation might have naturally occurred when microorganisms in the air acted on fallen starchy grains or fruits [3]. There are over 5000 fermented foods reported worldwide, with an estimated daily consumption of 50–400 g of fermented foods [4]. Fermented foods are produced using biochemical functions where microbes decompose or synthesize organic substances that positively affect the human body by producing new substances, such as organic acids, vitamins, fatty acids, and fragrances. In addition, the microorganisms involved in fermentation enter the human body and act as a probiotic, enhancing the value of fermented food products [5]. Hence, fermentation applicability will be broadened and extensively included in biotechnology and sectors associated with microbial culture in the near future [6]. The history of fermentation is the same as the history of microorganisms involved in fermentation. Between 3.3 and 3.5 billion years ago, microorganisms first appeared as life forms according to different proper survival conditions and began to use natural objects around them to maintain their lives [7]. Starting with these first microorganisms, a process in which numerous life forms appeared and disappeared was created.

However, it is necessary to understand how the fermentation process has evolved. From 10,000 B.C. until before the Aryan Middle Ages, fermentation techniques were employed to manage over-produced food items. Over the years, people learned multiple fermentation methods and experimented with other unique raw materials, such as meat and marine products. In this manner, acquired knowledge and techniques were passed down to future generations to form a unique fermented food. The general fermentation process is presented in Figure 1 [8].

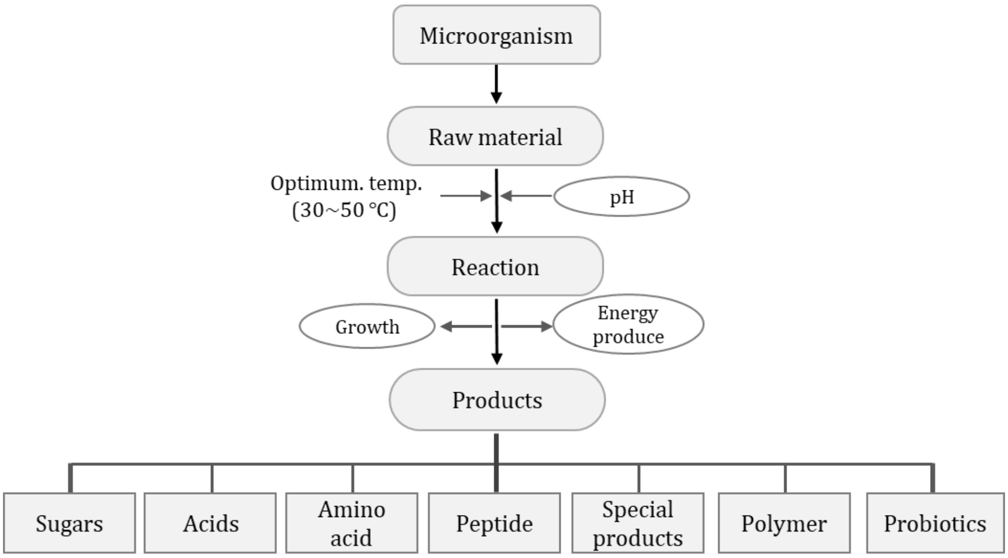

Figure 1. Enzymes released by microorganisms and the enzymes of the raw material.

2. Traditional Fermented Foods in Korea

The Korean diet relies on rice, specifically Hansik (Korean traditional diets), which forms the main meal. Hansik is composed of rice, soup, kimchi, and various banchan (side dishes) with one serving called bapsang. The principal aspects of Hansik include a proportionally high composition of fresh or cooked vegetables (namul), a moderate to high consumption of fish and legumes, and a low consumption of red meat. Banchan are different vegetable-based side dishes served with cooked rice in Korean cuisine. Various fermented foods are well suited to enhance the taste and are prepared using vegetables. However, it tastes bland and has a mild flavor and needs something salty to enhance the taste. Moreover, most available vegetables are also bland in taste and have a short lifespan. Thus, to enhance the taste and lifespan, salting was adopted [9]. With the introduction of salting into Korean cuisine, salted and fermented foods dominated the Korean diet as a side dish and gained popularity. Moreover, the salting process prevented the growth of putrefactive bacteria, facilitating an extended shelf life. With time, the salting process dominated food preparation and led to the development of several fermented foods. Since then, the Korean foods that best reflect the traditional fermentation process include kimchi, jang, jeotgal, and vinegar. These food products have dominated Korean food culture over the centuries.

2.1. Representative Traditional Korean Fermented Foods

2.1.1. Kimchi

Kimchi is one of Korea's signatory fermented foods prepared using various vegetables, including cabbage, fruits, and other ingredients. There are different types of kimchi depending on the raw materials and salting method. The preparation of good kimchi depends on the raw materials used, as these raw materials contain microorganisms needed for the fermentation process [10]. Additionally, the use of red peppers adds a unique taste to the kimchi, and its usage is unique to Korea [11].

2.1.2. History of Kimchi

Kimchi is one of the side dishes widely consumed in East Asia. It is estimated that kimchi was established as a food since the introduction of the salting method to the Korean diet. Early documents on kimchi can be retrieved from Samkuksaki, a book published in 1145 A.D. [12]. However, predicting the exact timing of kimchi's introduction is challenging, but the mixture of red peppers in kimchi can be linked to the traditional history of red peppers. Some historians claim that red peppers were imported before the Japanese Invasion of Korea in 1592, while others claim that red peppers have long been grown in Korea [13]. Despite these discrepancies, the history of kimchi is closely linked to the introduction of red peppers. Though kimchi is an outcome of a vegetable fermentation process in salt, it has undergone several transformations in its preparation [9]. Historically, kimchi was prepared with vegetables, such as cabbage, sweet potato, eggplant, dropwort, radish, leaf mustard, turnip, and lettuce, until the early Joseon Dynasty. In the 1500s, Suwoonjabbang, a book detailing cooking procedures, mentioned the use of these ingredients in making kimchi [14]. Moreover, Suwoonjabbang mentions the diversification of kimchi using red peppers, garlic, and jeotgal [15].

According to the Samguksagi (Korean history book), fermented foods, such as ganjang, doenjang, and sikhe were included in a bride's gift items when the third year of King Sinmun (683) greeted his wife, and it is believed to be a generic term for jeotgal and salted foods based on the record of jeotgal and salted vegetables. Additionally, a remaining relic named Seokong, in the 19th year of the 33rd King Seongdeok (720) at Beopjusa Temple of the Silla Dynasty, was assumed to be a jar for salting kimchi considering its shape. At this time, therefore, vegetable fermentation and fermented foods using fish as raw ingredients were already common, and they would have penetrated deeply into the Korean diet [16].

2.1.3. Types of Kimchi

All vegetables can be used as raw materials for producing kimchi. However, taste and flavor depend on how vegetables are pretreated, salted, and other ingredients, including spices, are added together. The major ingredient defines the type of kimchi that is produced. For instance, cabbage is the main ingredient in Chonggak kimchi, which has pickled ponytail radish, and Kkakdugi has cubed-cut radish. Other supplementary ingredients include red pepper powder, garlic, green onions, ginger, mustard, onions, and cinnamon, which add to the taste. Apart from these, other ingredients, such as dropwort, carrots, mustard leaf, crown daisy, radish leaves, and sesame leaves, are used depending on the taste of the region and family. Occasionally, sticky rice and malt extract are added to kimchi to give it a sweet taste. However, the main ingredient determines the type of kimchi produced, and it is used as per the regional taste [10].

2.1.4. Preparation of Kimchi

Kimchi preparation is simple, but requires quality raw materials to produce the best kimchi. Raw materials (cabbage, radish, and cucumber) are cut into appropriate sizes, and about 10% of salt is added to the raw material, either directly or indirectly. The direct addition of salt to the raw material is called dry salting, while raw materials being dipped in saltwater is a wet method. After brining, excess water is drained and the raw materials are remixed. The mixed raw materials are stored in containers for short-term or long-term fermentation periods. Seasoning for kimchi is prepared in advance by mixing spices, salted fish, red pepper powder, garlic, ginger, and seasoned vegetables. If seasoning is used, the amount of salt added is adjusted accordingly. Generally, a salt concentration of 2–3% is considered adequate. The combination of seasoning has a great influence on the taste of kimchi, but the moisture content in the raw material significantly influences the final product. Kimchi is a popular food product all over the world. Hence, low-temperature fermentation is preferred for commercial production. The general process for preparing cabbage kimchi is presented in Figure 2. Kimchi preparation is simple but different from German sauerkraut and Chinese Po Chai, which do not use special seasoning.

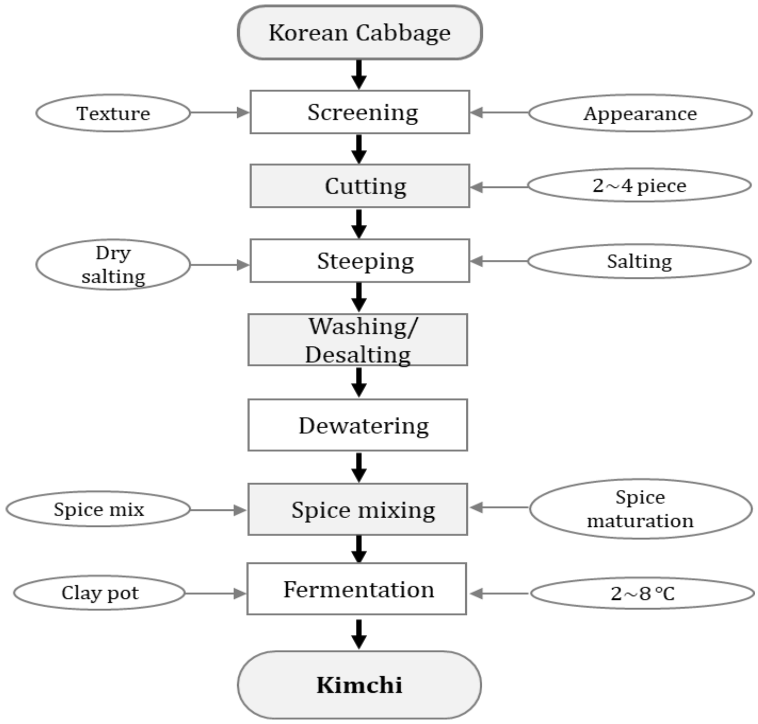

Figure 2. Simple manufacturing process of Korean cabbage kimchi.

2.2. *Jang (Fermented Soybean Products)*

Soybean is the primary raw material used to prepare jang, along with grains, red peppers, and salt. Historically, Dong Yi, an ethnic group from South Manchuria and mount Baekdu in the Korean peninsula, are thought to have been the first to use soybeans for food preparation [17]. However, amino acids or peptides are formed when the protein is decomposed by enzymes or other methods, which are water-soluble substances and impart distinct savory properties. Jang usage in Korea is described in Samguksagi (A.D. 683), but Chinese literature and relics suggest that soybeans were used in Korean cuisine much earlier than in 683 A.D. [18]. Nonetheless, multiple archaeological digs have proven that soybeans were used in the northern Korean Peninsula (Gyeonggi) in the late 2000s B.C. (Bronze Age) (Lee, S.W., 1994). These documents show that soybean farming began in the Korean peninsula during the Bronze Age, and some relics, such as the Baekje tombs, support this theory [9]. At present, there are several types of soy foods available, including ganjang and deonjang.

2.2.1. Production of Meju (a Brick of Fermented Soybeans)

Meju is the basic material for making jang. Traditionally, meju is made by allowing numerous microbes to naturally proliferate at high temperatures, and these microorganisms can decompose the soybean proteins. Thus, the fermentation state of meju is closely related to the quality of the final jang. Figure 3 depicts the meju preparation process [19].

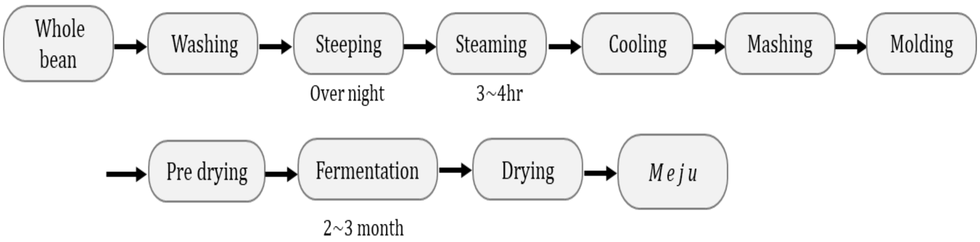

Figure 3. Procedure for the preparation of meju.

The taste and aroma of the meju depend on the degree of fermentation. However, recent developments and an increased understanding of fermentation has eased meju production. Recently, superior beneficial microorganisms have been utilized for inoculation and fermentation in the production of meju. At present, *Aspergillus oryzae* and *Bacillus subtilis* are common microbes used for the fermentation process.

2.2.2. Ganjang

In the Korean diet, ganjang is a popular, traditional, seasoned product. It is a household name in Korea and is generally prepared by homemakers to enhance the flavor of foods consumed with ganjang. Figure 4 illustrates the art of preparing ganjang [19].

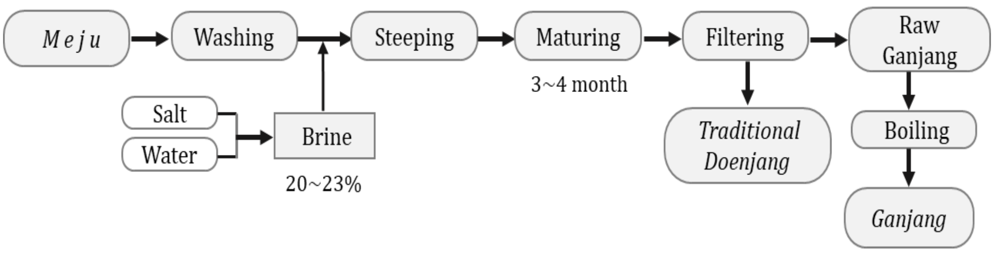

Figure 4. Schematic representation of ganjang preparation.

Ganjang prepared with a high salt (>20%) amount has a longer shelf life. Freshly prepared ganjang is known as haet ganjang (new soy sauce). Ganjang darkens, and the scent lightens with storage time. In addition, in some regions, modified ganjang is produced using flour and soybeans instead of meju. The preparation process for modified ganjang is presented in Figure 5 [20].

2.2.3. Doenjang

Doenjang is another food product made from soybean, and is traditionally used in Korea as a basic seasoning. In the market, doenjang is produced in two ways: one is traditional, and the other is a modified method [21]. Traditionally, doenjang is prepared by immersing meju in a brine solution and allowed to ferment for at least 6 months, then separated the remaining meju chunks. The filtrate becomes traditional ganjang. Traditionally, doenjang is prepared by the fermentation of cooked and mashed chunks with meju powder, ganjang, and steamed rice or barley in a clay pot. Specific microbes are inoculated to alter the fermentation process in the modified method. Ganjang is obtained as a byproduct of doenjang. Traditional doenjang has a unique and strong flavor. However, doenjang prepared using a modified method has a mild flavor. Traditional doenjang contains a relatively high salinity level, and efforts are being made to lower salinity without affecting the shelf life. The traditional and modified doenjang production is illustrated in Figures 6 and 7, respectively.

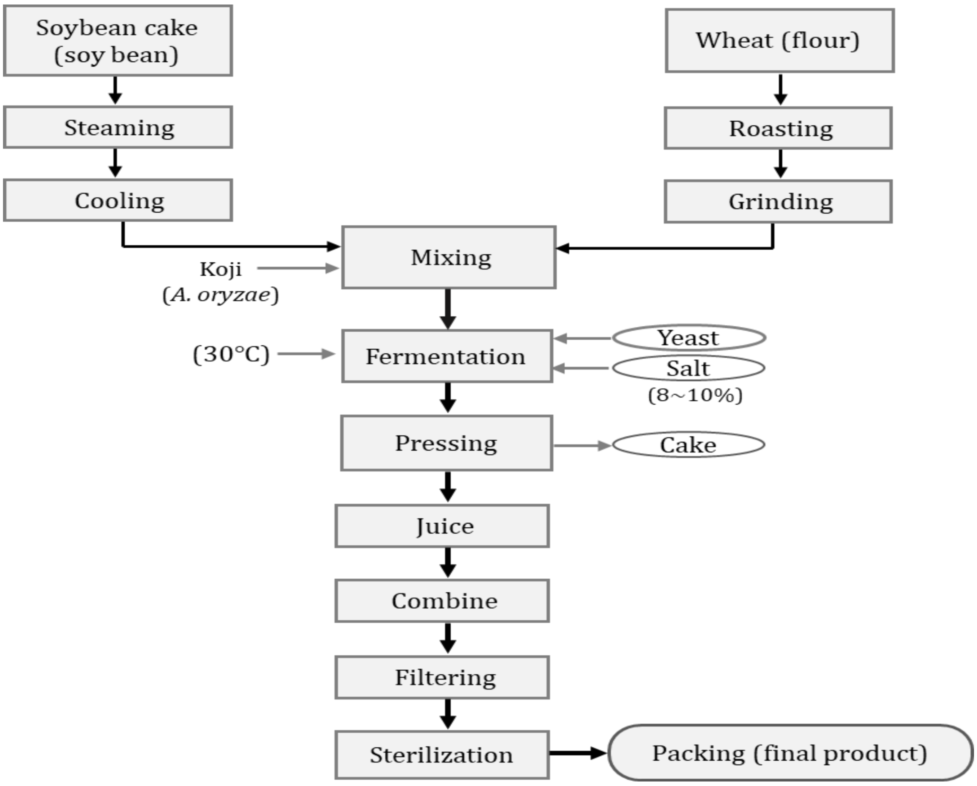

Figure 5. Manufacturing process of modified ganjang.

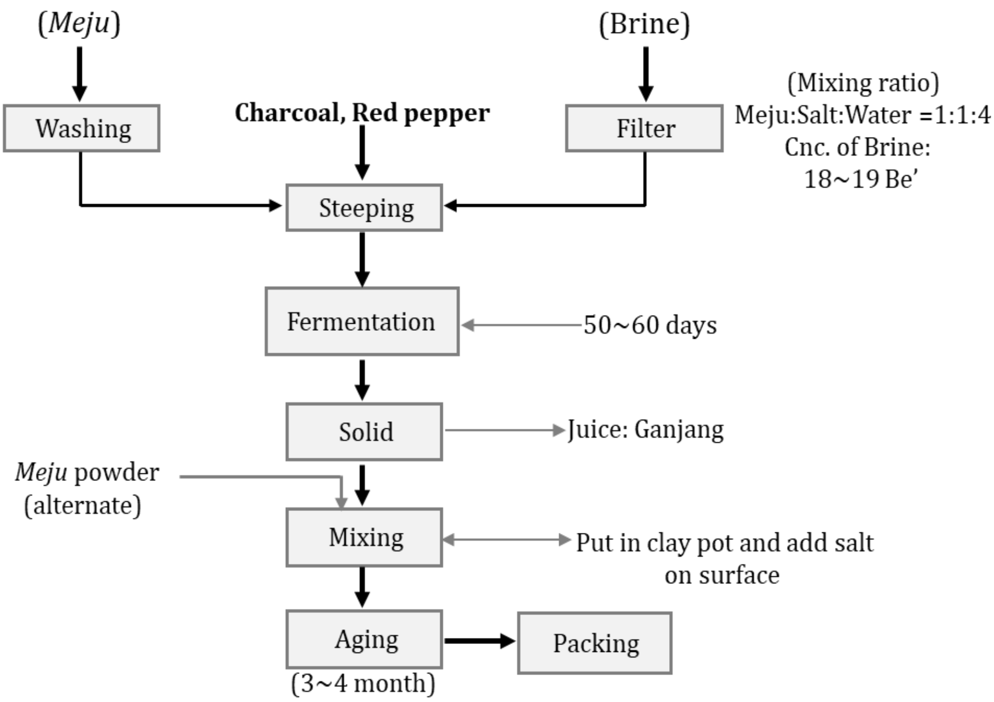

Figure 6. Traditional doenjang preparation.

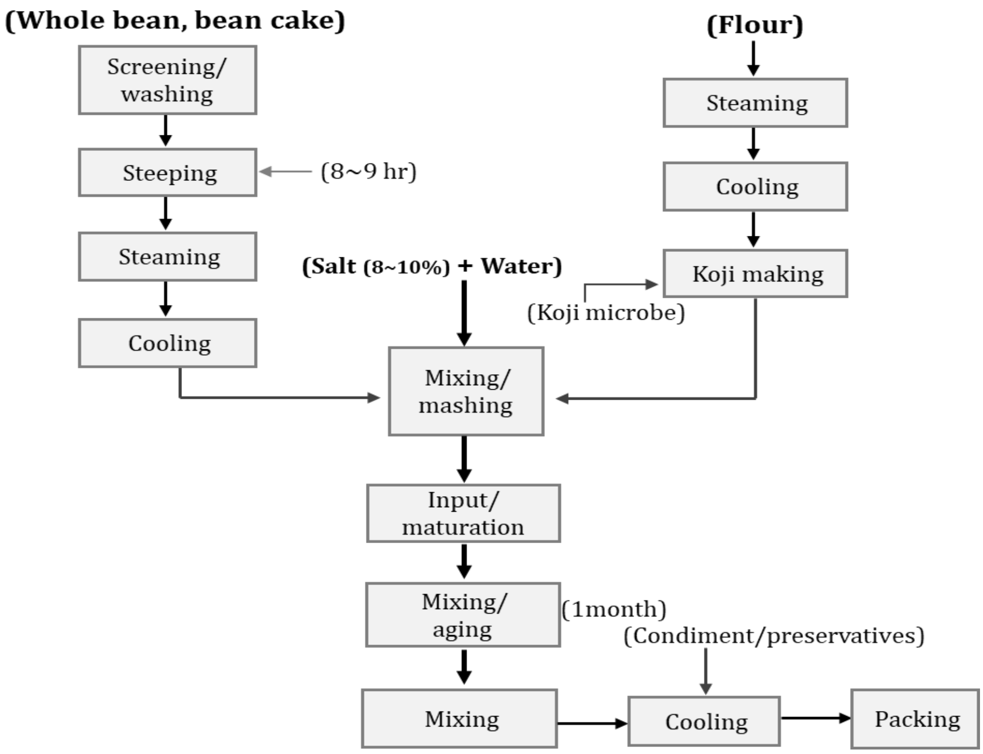

Figure 7. Modified doenjang preparation process.

Doenjang is reported to have antioxidant, anticancer, estrogen activity, and immunomodulatory properties. The presence of isoflavones in doenjang is responsible for these functional properties. Isoflavones exist in the form of hydrolyzed aglycone, which is rapidly digested and absorbed. Additionally, the absorption and bioavailability of aglycone are greater than the isoflavone glycosides [22].

2.2.4. Gochujang

Gochujang is a unique seasoning, and it is not only an item that can store well, but is also a spice-fermented seasoning that is differentiated due to its originality, such as its characteristic spicy taste and aroma. Red pepper and mustard are used as main ingredients worldwide, but several kinds of red peppers are also one of the most widely used spices. In particular, red pepper is differentiated by its refreshing, spicy taste and have recently been in the spotlight as a popular diet food worldwide. Along with kimchi, the perception of gochujang, a traditional Korean spicy food, is expected to change considerably. Figure 8 illustrates the general manufacturing process of traditional gochujang [19].

The addition of gochujang meju powder prior to fermentation and the use of malt extract to saccharify starch from grains are signatory processes during the preparation of gochujang. Gochujang preparation is characterized by long fermentation in a clay pot with an increased amount of red pepper powder. Sikhye gochujang is a traditional gochujang made with malt extract to break down the starch in rice and other grains, which produces a sweet taste. The modified process of preparing gochujang is presented in Figure 9 [23].

As shown in Figure 9, the modified process uses flour as a starch source. Starch is decomposed with koji enzymes during a shorter fermentation period. Additionally, the red pepper powder used during the modified gochujang process is less than 10% and added before or after fermentation. Traditional and modified gochujang has a distinct flavor, but modified gochujang is gaining popularity due to its low price.

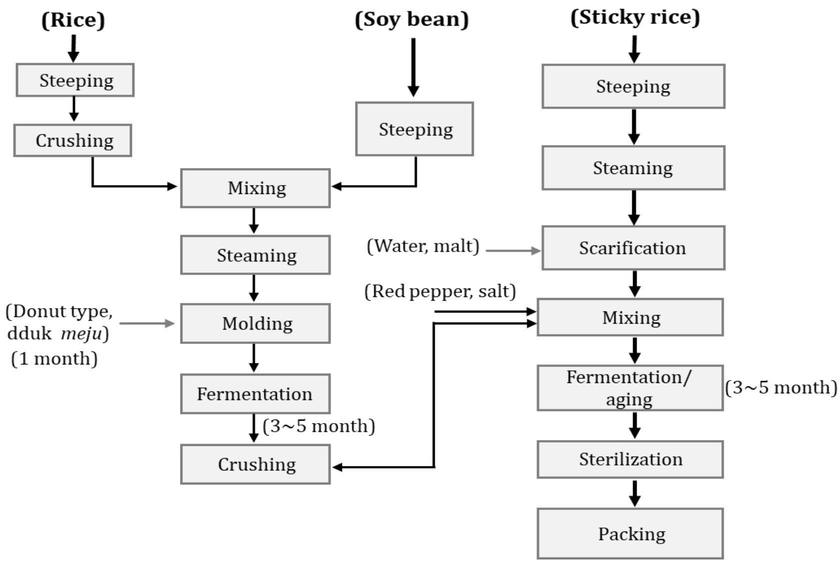

Figure 8. General manufacturing process of traditional gochujang.

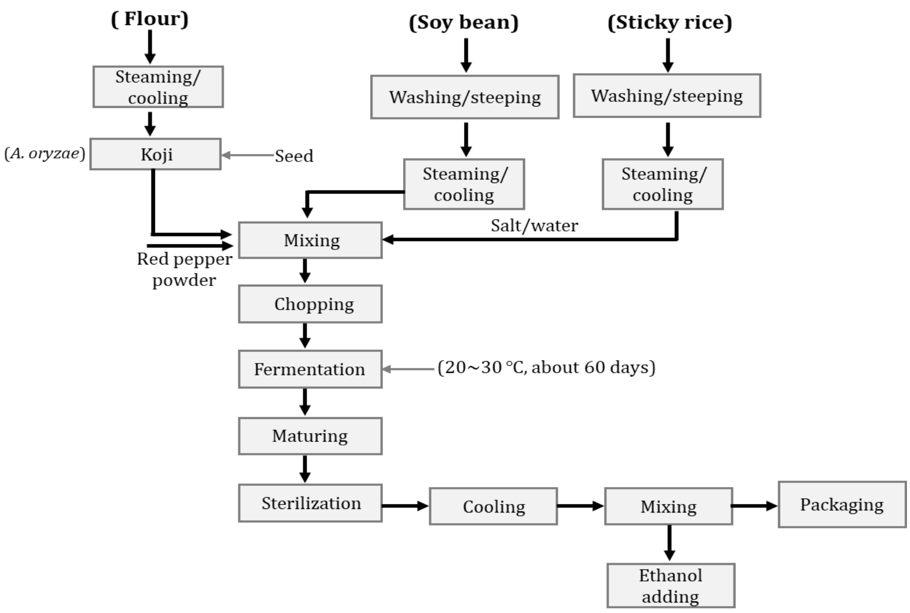

Figure 9. General manufacturing process of modified gochujang.

2.2.5. Cheonggukjang

Cheonggukjang is another fermented product produced from soybeans, and uses the power of bacteria to decompose the soybean protein [15]. Cheonggukjang is fermented at a high temperature (40–43 °C) for a short duration (2~3 days). In most cases, the bacterial composition is utilized to aid the cheonggukjang fermentation process. *Bacillus natto* is used to prepare Japanese natto, a fermented product from Japan similar to cheonggukjang. However, *Bacillus subtilis* is a bacteria commonly used to prepare cheonggukjang [24]. Cheonggukjang has a distinct fermentation odor and is consumed in the form of a stew or soup. However, cheonggukjang is unpopular among the young Korean generation owing to its distinct fermentation odor. Nonetheless, if this odor is refined or altered, then cheonggukjang can be developed as a favorite side dish worldwide. Figure 10 represents the manufacturing process for traditional cheonggukjang [19].

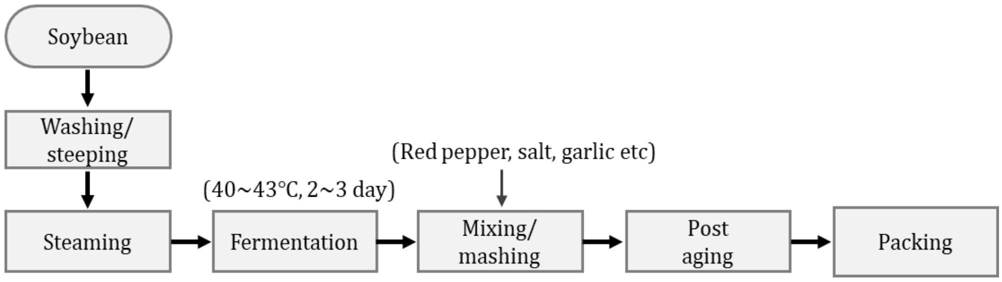

Figure 10. General manufacturing process for traditional cheonggukjang.

Moreover, the production of modified cheonggukjang involves the use of selected microbes for fermentation under certain fermentation conditions to regulate and equate the quality of modified cheonggukjang to that of traditional cheonggukjang.

2.2.6. Other Products

Traditionally, meju is the major raw material used along with vegetables and grains to make ssamjang, jeubjang, dambukjang, and makjang. However, the final product varies according to the ingredients used and fermentation conditions [25]. Ssamjang is based on doenjang with seasoning ingredients, such as gochujang. Jeubjang is made of meju, while jeupjang uses wheat flour and is fermented with dried eggplant, cucumber, and radish. It is generally prepared in the Jeolla-do and Gyeongsang-do regions. However, it is being prepared throughout Korea with minor modifications. Dambukjang is another fermented product prepared using meju powder, red pepper powder, and ganjang. Mkajang is processed using warm, glutinous rice with meju powder and fermented overnight. Then, ganjang and water are added and then fermented for about 15 days. Yukjang is another fermented product that uses chicken or meat, along with meju powder. Most of these products are similar, with slight modifications in their preparation process. Additionally, these products are region-specific and popular among adult Koreans.

2.3. *Jeotgal*

Salted and fermented fish products (jeotgal) have an organizational relationship with traditional Korean fermented foods. Jeotgal has a high salt content similar to other fermented products, and is used to enhance flavor and appetite. Jeotgal products are similar to jang, while sikhae resembles the characteristics of kimchi due to the similar fermentation process. The presence of several amino acids and minerals gives jeotgal a distinct flavor and taste. Fish is the main raw material used for jeotgal, but several shrimps, mollusks, squids, octopuses, and other crustaceans are also used for the preparation. Thus, the flavor and nutritional value of jeotgal are incomparably diverse [26]. Jeotgal is Korea's own traditional food, and various products resemble jeotgal in neighboring Japan, Southeast Asia, Mediterranean coastal countries, and European coastal countries. In Korea, jeotgal is typically presented as a side dish. However, it is an appetizer in the Mediterranean and other regions. Similarly, Japan uses jeotgal as a side dish for alcohol. Jeotgal has a historical socio-cultural background and is deeply embedded in Korean cuisine, but its consumption rates have remained stagnant over the years due to its high salinity level and unique, fishy smell.

2.3.1. History of Jeotgal

Jeotgal has a long history, and its usage is acknowledged in several literary works. According to the literature, Samkuksaki, a book on foods, documents the use of jeotgal in the dietary aspects of royal life during the Shilla Dynasty. However, over the years, its preparation has been transformed. The Sejongsilrokjiriji, Annals of King Sejong and Geography, and Chosunwangjosilrok, Annals of the Chosun Dynasty, mention the use of pork, rabbit, and deer with cooked grains and red pepper powder to prepare jeotgal. Liquified jeotgal has also been documented in the literature, but its characteristics are identical to classical jeotgal. Several Kingdoms discussed and presented hae and yukjang, terms for salted or fermented meat products in those days [27].

2.3.2. Types of Jeotgal [28]

Historically, jeotgal is prepared in several ways using various ingredients. There are various types of jeotgal depending on the raw materials used for the preparation [29]. However, basic, raw materials are subject to change depending on the occasion or celebration. Broadly, fermented salted fish is called jeotgal, fermented salted fish with spices is yangyup jeotgal, aekjeot is purified fermented liquid, and fermented salted fish with grains and spices is called sikhae [30]. Usually, a sweet drink made by saccharified rice with malt extract is called hyae (醯), and jeotgal is also called hae (醢) or ja (鮓). Jeotgal basically suppresses abnormal fermentation and decay by adding salt to fish, and fish protein is decomposed by the action of microorganisms mixed with the enzymes included in the fish itself, giving it a unique taste and flavor.

The raw materials used for making jeotgal include general fish, such as anchovies; hairtail and mollusks, such as squid, octopus, and oysters; and crustaceans, such as crabs and shrimps. Except for a few fish, most fish can be used as raw materials for making jeotgal. In the production of jeotgal, not only enzymes in the fish itself, but also various microorganisms are involved in its fermentation process. For instance, Micrococcus, Brevibacterium, Bacillus, Pseudomonas, Flavobacterium, lactic acid bacteria, and yeast are also involved in this fermentation.

2.3.3. Manufacturing Method and Ingredients of Jeotgal

Approximately 20% of salt is added to fish flesh during preparation of jeotgal, while roughly 10% is used in jeotgal with Alaska pollack. Specifically, jeotgal with 10% salt is stored in refrigerated conditions, and jeotgal with 20% salt is stored at room temperature for optimum shelf life. However, efforts are being made to simultaneously lower the salt content and increase the shelf life. The general preparation and production process of jeotgal is illustrated in Figure 11 [28].

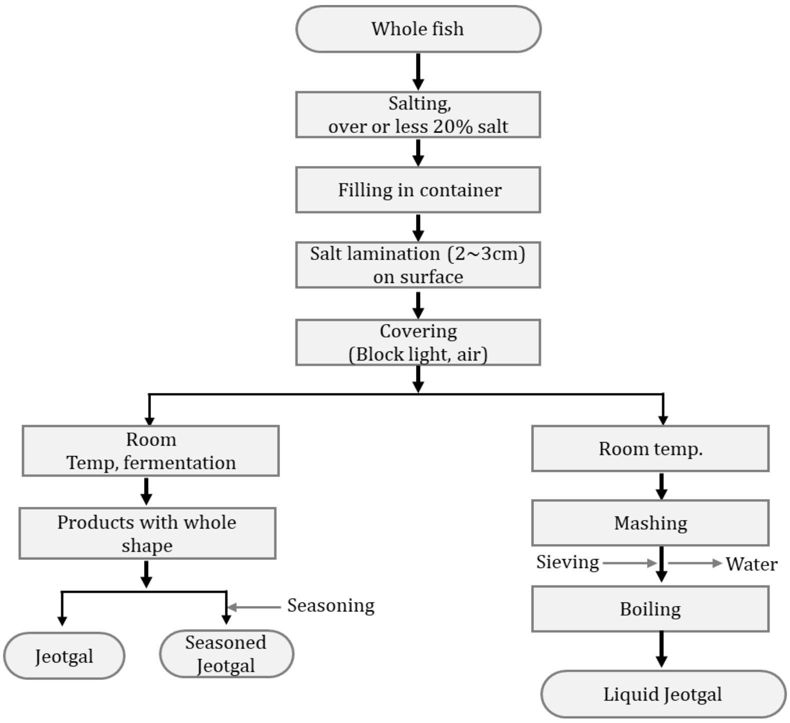

Figure 11. General manufacturing process of jeotgal.

The preparation of jeotgal is simple, but the quality of the product may vary depending on the quality of fish, salt content, and fermentation method. Nonetheless, a high salt content needs to be reduced to address salt-related health concerns. Additionally, manufacturing techniques need to be improved to enhance the cleanliness of the jeotgal.

Properly aged jeotgal rarely smells fishy and has a savory flavor characteristic of fermented foods, along with an increased essential amino acid content. However, partially fermented jeotgal has a fishy smell with a sulfur or dimethylamine (DMA) odor, and has a high ammonia content. These characters significantly reduce the acceptance of jeotgal as food. The lipid component of the raw material is susceptible to change into peroxide with unpleasant flavors during fermentation and aging, and is decomposed into volatile and nonvolatile fatty acids representing various flavor properties under the influence of lipase [30]. Moreover, glycogen or free sugars of raw material can be converted into organic acids or alcohols during fermentation and aging processes. Jeotgal inhibits most bacteria. However, salt-tolerant microbes can be found extensively in the product. Table 1 compares the characteristics of jeotgal and ganjang [31].

Table 1. Characteristics of jeotgal and ganjang (%).

Contribution	Jeotgal (Liquid Type)		Ganjang (Soybean)
	Range	Average	
pH	5.3–6.7	6.0	4.7–4.9
Salt	22.5–29.9	26.2	16.0–18.0
Total amino acid	2.9–7.7	5.3	5.5–7.8
Glutamic acid	0.38–1.32	0.85	0.9–1.3
Total organic acid	0.21–2.33	1.27	1.4–2.1
Acetic acid	0–2.00	0.87	0.1–0.3
Lactic acid	0.06–0.48	0.27	1.2–1.6
Succinic acid	0.02–0.18	0.10	0.04–0.05
Reducing sugar	Trace	Trace	1.0–3.0
Ethanol	Trace	Trace	Trace

As shown in Table 1, jeotgal has a pH of 6, whereas ganjang has a pH of 4.8, indicating a substantial difference in pH levels. Similarly, jeotgal has a substantially higher salinity level than ganjang.

2.4. Vinegar

Vinegar is one of the oldest fermented foods in Korea. It has been used as seasoning and in various homemade remedies [32]. Vinegar has a refreshing, sour taste and is known to stimulate appetite. Traditionally, it is produced using natural fermentation using alcoholic beverages, such as makgeolli (alcoholic liquor using rice). Moreover, vinegar can be produced legally by diluting synthetic acetic acid [33]. Generally, it is prepared through alcohol fermentation followed by acetic acid fermentation induced by inoculating acetic acid bacteria. Thus, the vinegar marketed in Korea consists of both naturally produced vinegar and acetic acid vinegar.

2.4.1. History of Vinegar

Western countries believe that vinegar has been in use since 5000 B.C. In the beginning, grapes and apples were fermented in a natural environment where microbes in the air played a critical role in producing vinegar [34]. In Babylon, the earliest fruit vinegar was produced by fermenting date palms and was used for seasoning, food storage, and medical purposes [32]. Balsamic vinegar was produced by Romans in the 17th century, especially in Montana. Jeminyosul, a classic Chinese agricultural book, reveals that vinegar has been used in the East for over 3000 years, and is made from fruits and alcoholic/fermented grains of various colors, including red, brown, and black [35]. The origin of vinegar in Korea is unknown. However, it is believed that it could have been in use since the discovery of alcohol fermentation. In Jibongyuseol, vinegar was also described as a liquor with a bitter taste. Various records show the presence and use of vinegar in Korea. For example, cherry was said to have a taste similar to vinegar in Goryeodogyoung, as a cooking ingredient in Haedongyuksa, and as a medicine to treat cramps or strokes in Hyangyakgugeupbang. Furthermore, in the Joseon Dynasty, vinegar fermented with barley in Gosacharlyo and Donguibogam alleviated carbuncles, blood clots, heartache, and pains. The ancient book introduced vinegar and explained how to make it, and there are various kinds of vinegars [36]. The records indicate that Japan imported vinegar from China in the 5th century and during the Pyeongan era (794–1192). Then, from the Kamakura (1185–1333) to the Muromachi (1336–1573) periods, vinegar was a representative seasoning. During the Edo period (1614–1615), vinegar was widely used with sushi [36]. Table 2 illustrates the various medicinal applications of vinegar throughout history [32].

Table 2. Medicinal usage of vinegar.

Category Used	Ingredient	Applied Disease
Ancient Assyrian	Vinegar	Ear infection
Ancient Persian	Citrus, lime vinegar	Reduce body fat
Greek, Roman	Vinegar	Digestive stimulant, scurvy
Spartan	Vinegar	Stamina replenishment
Middle Ages	Herb (lavender, rosemary) vinegar	Upset stomach, headache
Garenos	Honey, vinegar	Couch
British	Vinegar	Mouthwash
Hippocrates	Vinegar, honey, pepper	Expectorant action, female disease
Egypt	Vinegar	Beauty, poor eating

At present, the perception of vinegar is changing as it is consumed as a drink. This shift in perspective indicates that its customer base extends beyond its traditional use as a food seasoning. Moreover, vinegar is slowly making its way into the beauty product market, which could be the start of a new developmental phase for vinegar.

2.4.2. Types of Vinegar

Grain and fruit vinegars are two major types of vinegar based on the raw materials used for production. Other types of vinegar are also available, but their consumption is limited. For example, vinegar produced using medicinal herbs with other supplementary ingredients has a limited local market. Generally, brown rice, white rice, sorghum, barley, wheat, and millet require the saccharifying process to be used as raw materials for vinegar. Contrastingly, fruits do not require the saccharifying process and can be used directly for vinegar preparation. Together, it can be concluded that the type of vinegar depends on the primary ingredient employed in the production process. Table 3 illustrates the applications of vinegar and its respective market potential.

Table 3. Classification of vinegar by use and market conditions.

Division	Raw Material and Usage	Product Type	Market
Seasoning vinegar	Seasoning for cooking Produced by alcohol fermentation or dilute glacial acetic acid	Brewed vinegar, apple vinegar, synthetic acetic acid	Large company occupies large portion Some special products produced by small manufacturer
Vinegar for health	Low concentration of acid for direct drinking or drink after dilution Use grains, persimmon, grape, and other fruits	Fruit vinegar (persimmons, grapes, etc.) and brown rice	New market is formed by some manufacturer

2.4.3. How to Make Vinegar [37]

The process of vinegar fermentation is as simple as other fermented products in Korea. Fruits do not require the saccharifying process and can be used directly for vinegar preparation. However, grains should pass a saccharifying process triggered by yeast. Firstly, alcohol is produced through fermentation, and the alcohol produced is utilized to create acetic acid using acetic acid bacteria. The traditional preparation process for vinegar is presented in Figure 12. Various types of vinegars with different tastes and aromas are produced using different raw materials.

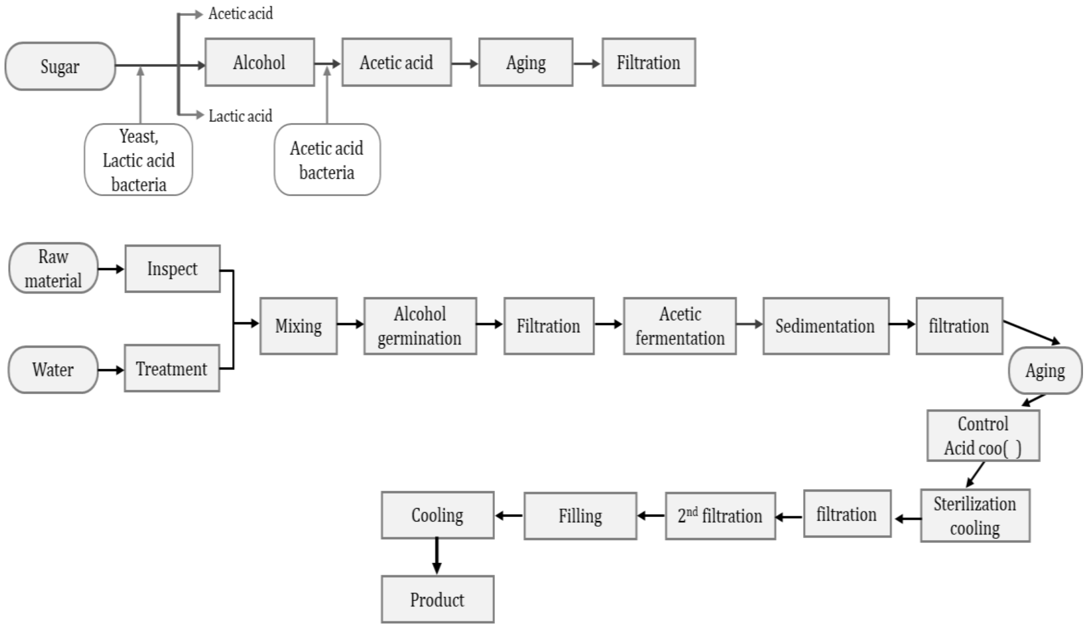

Figure 12. General preparation process for vinegar.

2.4.4. Acetic Acid Bacteria

The bacteria involved in producing acetic acid through oxidizing ethanol are generally referred to as acetic acid bacteria. These bacteria are Gram-negative and aerobic, belonging to the genus of *A. cetobacter*. Some important bacteria in this family include *A. aceti, A. acetosum*, *A. mesoxydans*, *A. rancens*, *A. viniacetati, A. orleans*, alcohol vinegar includes *A. aceti*, and *A. acetigenum*. These bacteria are available for purchase as pure bacteria. However, these bacteria can be isolated during traditional preparations and utilized in subsequent preparations or stored as stock culture. Additionally, bacterial species, such as *A. oxydans* and *A. suboxydans*, are unsuitable for the production of vinegar as they tend to produce fibrous mucous membranes during fermentation. During mass production, the choice of strains greatly affects the production yield and quality.

2.4.5. Vinegar Fermentation and Ripening Methods [38]

There are various types of fermentation methods used for the preparation of vinegar. Surface fermentation, agitated fermentation (air injection into a tank), and submerged fermentation methods are popular vinegar fermentation methods. The static method is simple and can be used to create vinegar at home. However, it is challenging to regulate temperature, humidity, and aeration, which might influence the vinegar's quality. Thus, it is not suitable for mass production, but could be used to produce unique vinegar with a distinct flavor. Despite several limitations, Koreans showed wisdom in managing fermentation conditions. In the West, vinegar is fermented using Orleans or French processes, where the static surface fermentation method is adopted. The liquid fermented as vinegar usually undergoes a ripening process for a considerable period of time due to the degradation of taste because of its unique, pungent smell of acetic acid. It usually takes two to three months, and it is purified by the reaction of the contents of the acetic acid and fermentation liquid produced at this time to produce aromatic substances, such as ethyl acetate. Additionally, the precipitation of undissolved proteins, pectin, and starch clears the liquid.

2.4.6. Ingredients of Fermented Vinegar

Vinegar is a combination of acetic acid and water. However, other organic acids, such as fumaric, lactic, α-ketoglutaric, succinic, malic, and gluconic acids are used for the preparation of vinegar. Additionally, several aromatic components are used along with the acids.

3. Health Benefits of Korean Fermented Foods

Korean ancestors and descendants mastered the fermentation technique and developed popular fermented foods, such as kimchi, jang (ganjang, doenjang, gochujang, and cheonggukjang), jeotgal, and vinegar. Additionally, several illnesses are traditionally treated with these fermented foods. Recently, these fermented foods have been recommended for a healthy diet, and their health benefits have been demonstrated and reported in [39]. Table 4 presents the major studies demonstrating the health benefits of traditional, fermented foods.

Table 4. Studies showing the relationship between fermented foods and health benefits.

Fermented Products	Functionality	Study Types	Consumption	Health Effects of Fermented Foods	References
LAB (lactic acid bacteria) isolated from kimchi	Oxidative stress	In vitro	*Lactobacillus* sp. (*L. sakei* JK-17)	• Radical scavenging activity, DPPH, ABTS radical • *L. sakei* JK-17 culture depleted nitrite concentration 94.75%	[40]
LAB kimchi	Anti-bacterial	In vitro	*Lactobacillus planetarium* (KC23)	• *L. plantarum* KC23 exhibited antibacterial activity as it formed a clear zone of 8–13 mm for the 5 pathogens	[41]
LAB kimchi	Anti-bacterial	In vitro	*Leuconostoc* sp.; lactic acid bacteria isolated from kimchi (KLAB)	• Raw 264.7 macrophages: effective for the generation of NO, TNF-α, and IL-6 in macrophage	[42]
LAB kimchi	Mutagenicity/toxicity	In vitro	*Lactobacillus* sp. (kimchi Lactobacillus strains)	• Nitrite depletion, aflatoxin binding	[43]
LAB kimchi	Diabetes	In vitro	*Leuconostoc* sp. (meenteroides KFRI73007) (Lactic acid bacteria isolated from kimchi)	• Lower β-glucosidase activity	[44]
LAB kimchi	Skin protection	In vivo	Hairless mouse: *Lactobacillus* (lyophilized Korean cabbage kimchi, mustard leaf kimchi, and Buchu kimchi)	• Skin pH improvement • Chlorophyll contents in buchu and mustard leaf kimchi were higher than cabbage kimchi. Contents of carotene and ascorbic acid were higher in the mustard leaf kimchi	[45]
Kimchi	Serum lipids and blood glucose	RCT	Male and female, n = 100; High-kimchi (210 g/d)-intake vs. low-kimchi (50 g/d)-intake groups; 7 days	• TC and LDL-C were significantly decreased in the high-kimchi-intake group • Fasting blood glucose was significantly decreased in the high-kimchi-intake group as compared to the low-intake group	[46]
Kimchi	Anti-atherosclerosis	RCT	Male and female, n = 12; kimchi pill; 3 g/day; 6 weeks	• Lower TG, LDL/HDL-C, and atherogenic indexes	[47]
Kimchi	Intestinal microbiota	RCT	Female, n = 12; kimchi; 150 g/day; 7 days	• Beneficial effects the formation of intestinal microbiota	[48]
Kimchi	Intestinal microbiota	RCT	Male and female, n = 10; kimchi; 200 g/day; 4 weeks	• Intake of 200 g of kimchi per day for four weeks in adults is known to lower the concentrations of β-glucosidase and β-glucuronidase that cause colon cancer	[49]
Kimchi	Iron status	RCT	Male, n = 12; kimchi, 300 g/day; 4 weeks	• Lower serum iron and serum ferritin	[50]

Table 4. *Cont.*

Fermented Products	Functionality	Study Types	Consumption	Health Effects of Fermented Foods	References
Kimchi	Intestinal microbiota	RCT	Female, n = 24, obese women, fermented kimchi, 180 g/day, 8 weeks	• Beneficial effects of blood gene expression and gut microbial population ⇨Kimchi intake was accompanied by a decrease in genus Blautia and an increase in *Prevotella* and *Bacteroides* in the gut microbial population	[51]
Kimchi	Obesity metabolic parameters	RCT	Male and female, n = 22; overweight and obese adults; fermented kimchi; 300 g/day, 4 weeks	• Lower systolic and diastolic blood pressures, percent body fat, fasting glucose, and TC, compared with the fresh kimchi	[52]
Kimchi	Metabolic parameters	RCT	Male and female, n = 21; pre-diabetic men and women; fermented kimchi; 100 g/day; 8 weeks	• Effects BP and insulin-resistance sensitivity • Decreased body weight, BMI, and waist circumference Fermented kimchi decreased insulin resistance and increased insulin sensitivity • Decreased systolic and diastolic blood pressures	[53]
Kimchi	Metabolic parameters	RCT	Female, n = 38; obese middle-school girls; fermented kimchi capsules; 3 g/day; 6 weeks	• Lower weight, BMI, fat mass, abdominal fat, TC, LDL-C, and TG	[54]
Kimchi	Metabolic parameters	RCT	Male and female, n = 39; functional kimchi (FK) vs. standardized kimchi (SK); 210 g/d; 4 weeks	• FK: lower IL-6, MCP-1 • FK: lower TG, TC, LDL-C, and higher HDL-C • FK and SK: increased adiponectin • FK: reduced the abundance of *Firmicutes*, but increased levels of *Bacteroidetes*	[55]
Kimchi	Immunomodulation	RCT, open	Male and female, n = 39; Chinese college students; fermented kimchi; 100 g/day; 4 weeks	• No effects on immunomodulatory functions	[56]
Kimchi	Irritable bowel syndrome	RCT, placebo	Male and female, n = 90; subjects of IBS symptoms; functional kimchi (FK) vs. standardized kimchi (SK) vs. dead nano-sized *Lactobacillus* plantorumnF1(nLp) added to standard kimchi; 210 g/d; 12 weeks	• All groups: increase in TNF-α • Serum IL-4, IL-10, and IL-12 levels significantly reduced in the nLp SK and FK groups • All groups: lower β-glucosidase and β-glucuronidase of fecal matter • Gut microbiome: increased *Firmicutes* populations at the expense of *Bacteroidetes*. • FK: acterium adolescentis population increased	[57]

Table 4. *Cont.*

Fermented Products	Functionality	Study Types	Consumption	Health Effects of Fermented Foods	References
Kimchi	Hypertension	Cross-sectional study	Korean adults n = 5932 (male: 2822, female: 3820) Age: 19–64 y	• Higher consumption of kimchi was not associated with a higher prevalence of hypertension (odds ratio = 0.87; 95% CI = 0.70–1.08 for ≥216.5 g/day vs. <39.2 g/day; p = 0.753) • High consumption of kimchi was not associated with an increased prevalence of hypertension in humans	[58]
Kimchi	Hypertension	Cohort study (a 12-year follow-up study)	Korean adults n = 5932 (male: 2822, female: 3110) Age: 40–69 y	• High kimchi consumption was not shown to be associated with increased risk of hypertension	[59]
Kimchi	Asthma	Cross-sectional study	Korean adults n = 19,659 (male: 7787, female: 11,872) Age: 19–64 y	• A significant inverse relationship between kimchi consumption and the prevalence of asthma •The prevalence of asthma in Korean adults was 2.4%. Adults with asthma consumed lower amounts of kimchi	[60]
Kimchi	Atopic dermatitis (AD)	Cross-sectional study	Korean adults n = 7222 (male: 50.9%, female: 49.1%) Age: 19–49 y	• Decreased odds ratio (OR) of having AD according to kimchi consumption • Consuming 85.0–158 g/day of kimchi significantly associated with a lower presence of AD	[61]
Kimchi	Rhinitis	Cross-sectional study	Korean adults n = 7494 Age: 19–64 y	• The prevalence of rhinitis decreased with increased kimchi consumption • The quintile 4 (range of kimchi intake: 108~180 g) groups, compared with the reference of quintile 1 (0~23.7 g), showed a decrease of 18.9%	[62]
Kimchi	Lipids profiles	Cross-sectional study	Korean adults n = 102 (male) Age: 40–64 y	• Kimchi consumption positively correlated with HDL-C and negatively correlated with LDL-C	[63]
Kimchi	Anti-oxidant	Cross-sectional study	Korean adult total: n = 335 Age (20–29 y): n = 146 (male: 55, female: 91) Age (65): n = 189 (male: 89, female: 100)	• The correlation coefficient between kimchi intake and total free radicals was 0.1862 (negative correlation) and that for GSH/GSSG was 0.1861 (positive correlation).	[64]

Table 4. *Cont.*

Fermented Products	Functionality	Study Types	Consumption	Health Effects of Fermented Foods	References
Ganjang	Hypertension	In vivo	SD rat: Fermented ganjang (salt 8%; GJ) General salt (table salt 8%; NC)	• Decreased blood pressure • The serum renin levels decreased in the GJ group compared to the control group, while the serum aldosterone level decreased in the GJ group relative to the NC group	[65]
Ganjang	Cancer	In vivo	C57 BL/6J mice Ganjang (Korean soy sauce), including acid-hydrolyzed soy sauce (AHSS), fermented soy sauce (FSS), and fermented sesame sauce (FSeS)	• Increase in immune cytokines • FSeS and FSS: decreased the serum levels of TNF-α, IFN-γ, IL-6, and IL-17α. mRNA expression • FSeS: anti-colitis effect partially by reducing the serum levels of pro-inflammatory cytokines and inhibiting mRNA expression	[66]
	Cancer	In vitro	Colorectal cancer: fermented soy sauce with added sesame seeds	• Increased the expression of colonic p53 • Tumor-suppressor gene indicating stronger anticancer effects	[67]
Ganjang	Antithrombotic	In vitro	Bacterial strains exhibiting fibrinolytic activity screened from traditional Korean soybean sauce	• Decrease in fibrinolytic activity	[68]
Ganjang	Antioxidant	In vivo	Wistar rats (rats fed high-PUFA oils)	• Protective effect of fatty acid oxidation	[69]
Ganjang	Immune/anti-inflammation	In vivo	RAW 264.7 cell and ICR mouse (polysaccharides isolated from commercial soy sauce (CSP-0) vs. traditional Korean soy sauce (KTSP-0))	• Both CSP-0 and KTSP-0 showed significantly higher IL-6 production rates than that of the untreated or CSP-0 groups. Decreased inflammation cytokines • KTSP-0 administration augmented IL-6 content in mouse sera, whereas CSP-0 did not show any effect on IL-6 induction	[70]
Ganjang	Antibacterial	In vitro	Streptococcus spp. causing dental caries in Korean soy sauce (NG 06 strain isolated from ganjang)	• Increased antimicrobial activity • The isolate NG 16 strain was confirmed as Gram-positive, rods, endospore production, utilization of melibiose, casein hydrolysis and starch hydrolysis	[71]

Table 4. *Cont.*

Fermented Products	Functionality	Study Types	Consumption	Health Effects of Fermented Foods	References
Doenjang	Cancer	In vivo	Balb/c mice (sarcoma-180 cell-transplanted mice) ⇨Doenjang fermented for 3, 6, and 24 months	• Increase in metastasis and natural killer cell activity (doenjang fermented for 24 months exhibited a two-to-three-fold increase in antitumor effects on sarcoma-180-injected mice and antimetastatic effects in colon 26-M 3.1 cells in mice compared with the 3- or 6-month-fermented doenjang)	[72]
Doenjang	Hypertension	In vitro	3T3-l1 adipocyte cells (treated with doenjang and RAS blockers, losartan (10−4 M) and captopril (10−4 M) were treated as positive controls, which suppresses AGT1R and ACE)	• Decrease in regulated RAS activity • Doenjang: decrease in ACE and angiotensin II receptor 2 (AGTR2) levels	[73]
Doenjang	Hypertension	In vivo	SD rats Fermented doenjang (salt 8%) General salt (table salt 8%)	• Increase in ACE-inhibitor activity	[74]
Doenjang	Antithrombotic	In vitro	Manufacturing method for traditional doenjang and screening of high-fibrin-clotting-inhibitory samples	• Regulation of fibrinolysis, fibrinogen clotting inhibition	[75]
Doenjang	Obesity	In vivo	C57BL/6N SD rats (fed basal (BA) (5% fat), high-fat (HF) diet (30% fat), HF + steamed soybeans (SOY), or HF diet + doenjang (DJ) ad libitum, 8 weeks	• DJ: decrease in visceral fat accumulation, adipocyte size • DJ: decrease in obesity gene expression (lowered the atherogenic index and serum leptin level)	[76]
Doenjang	Obesity	RCT, placebo	Overweight women (n = 51) 12 weeks, 9.8 g/day	• Decrease in body weight, body fat, and visceral fat	[77]
Doenjang	Obesity	RCT, placebo	Overweight women with the PPAR-γ2C1431T polymorphism (n = 51), 12 weeks, 9.8 g/day	• Decrease in visceral fat • Increase in antioxidant activity	[78]
Doenjang	Obesity	RCT, placebo	Overweight women with UCP-1polymorphism (n = 51), 12 weeks, 9.8 g/day	• Decrease in visceral fat • Increase in lipolysis, free fatty acid	[79]
Doenjang	Immune/anti-inflammation	In vivo	Male C57BL/6J mice: low-fat diet (LF), high-fat diet (HF), or a high-fat diet containing doenjang (DJ), or a high-fat diet containing steamed soy bean (SS) for 11 weeks	• Cytokine level regulation • Decrease in inflammation cytokine expression (reduced mRNA levels of oxidative stress markers, pro-inflammatory adipokines, macrophage, and a fibrosis marker)	[80]

Table 4. *Cont.*

Fermented Products	Functionality	Study Types	Consumption	Health Effects of Fermented Foods	References
Doenjang	Cognitive function (brain neuroprotection)	In vivo	C57BL/6J mice: a low-fat diet, HF diet, HF diet containing steamed soybean, or an HF diet containing doenjang (DJ), 11 weeks	• Doenjang: lowered β-amyloid peptide levels by regulating gene expressions involved in β-amyloid peptide production and degradation • Effectiveness of brain nerve protection	[81]
Doenjang	Anti-oxidant	In vivo	Commercial doenjang vs. traditional doenjang	•Traditional doenjang: increase in antioxidant enzyme activities and decrease in ROS level (radical scavenging activity: DPPH, ABTS, and TBARS)	[82]
Doenjang	Skin (whitening action)	In vitro	Melanin cell: o-Dihydroxy isoflavone derivatives in long-aged doenjang	• Decrease in o-Dihydroxy isoflavone derivative tyrosinase activity • Decrease in melanin formation	[83,84]
Gochujang	Cancer	In vitro	Traditional kochujang added to garlic porridge	• Decrease in cancer cell viability • Increase inf anticancer activity	[85]
Gochujang	Obesity	In vivo	Gochujang products prepared using rice *koji* and soybean *meju*	• Improved lipid profiles: lower TG • Decrease in obesity gene expression, body weight gains, epididymis fat weights ⇨ Inhibition of lipogenic enzyme's fatty acid synthase, malic enzyme, and lipoprotein lipase by gochujang products in epididymis adipose tissues, and inhibition of glucose-6-phosphate dehydrogenase in the liver	[86]
Gochujang	Obesity	RCT, placebo	Overweight women (n = 53), 12 weeks, 32 g/day	• Decrease in visceral fat • Decrease in serum TG and Apo B	[87]
Gochujang	Obesity	RCT, placebo	Overweight and obese adults n = 60, 3 weeks High dose of beneficial microbes of traditional kochujang (HTK) Low dose of beneficial microbes of traditional kochujang (LTK) Commercial kochujang (CK), 25.3 g (powder 19 g)	• HTK, CK group: decrease in WC • HTK, LTK group: decrease in TC, LDL-C, HDL-C, and TG • HTK: decrease in visceral fat • All groups: increase in beneficial microorganisms	[88]
Gochujang	Obesity	RCT, placebo	Overweight women with the PPAR-γ2C1431T polymorphism (n = 53), 12 weeks, 32 g/day	• Anti-obesity effects	[89]
Gochujang	Diabetic	In vivo	90% pancreatectomies diabetic rats	• Blood glucose regulation	[90]

Table 4. *Cont.*

Fermented Products	Functionality	Study Types	Consumption	Health Effects of Fermented Foods	References
Gochujang	Anti-atherosclerosis	RCT, placebo	Adult with hyperlipidemia (n = 30), 12 weeks, 35 g/day	• Decrease in TC and LDL-C • Increase in HDL-C	[91]
Gochujang	Immune	In vivo	Balb/c mice (RAW 264.7 cell)	• Improved immune cytokines	[92]
Cheonggukjang.	Digestibility (absorption)	RCT, placebo, Cross-over	Healthy adult (n = 10) Fermented soybean (FS) or non-fermented soybean (NFS) consumption, fresh chungkookjang, 1 day, 35 g/day	• Increase in serum isoflavone's absorption • Increase in bioavailability	[93]
Cheonggukjang.	Bone	In vivo	SD rat: Rubus coreanus-cheonggukjang (RC-CGJ), general cheonggukjang (CGJ), control group, 9 weeks	• Increase in spine bone mineral density (significantly higher in the RC-CGJ and CGJ groups)	[94]
Cheonggukjang.	Anti-atherosclerosis	In vivo	Recombinant cheonggukjang kinase (CGK) 3–5-rich fraction as a thrombolytic agent, which we overexpressed in *Bacillus licheniformis* ATCC10716	• Fibrinogen clotting inhibition (CGK3–5-rich fraction inhibited collagen-induced platelet aggregation in platelet-rich plasma in a concentration-dependent manner)	[95]
Cheonggukjang.	Anti-atherosclerosis	RCT, placebo, cross-over	Overweight adults (n = 83), 12 weeks, 35 g/day	• Male: increase in Apo A1 • Female: decrease n Apo B	[96]
Cheonggukjang.	Anti-atherosclerosis	RCT, 3 arms	Adults with impaired fasting glucose (n = 30), 8 weeks Cheonggukjang (CH) vs. red ginseng Cheonggukjang (RGCH) vs. control group (starch), 20 g/day	• CH group: decrease in Apo B/A ratio • CH, RGCH group: improvement of lipid profiles	[97]
Cheonggukjang.	Obesity	In vivo	C57BL/6J mice (fermented with poly-gamma glutamic acid producing *Bacillus licheniformis*-67), 13 weeks	• Decrease in weight gain (body weight and epididymis fat pad weight in 30% cheonggukjang)	[98]
Cheonggukjang.	Obesity	RCT, placebo, cross-over	Overweight adults (n = 83), 12 weeks, 35 g/day	• Improved obesity index	[96]
Cheonggukjang.	Diabetic	In vivo	STZ-induced diabetic rats (soybean cheonggukjang, yakkong cheonggukjang, and black foods, such as black rice, black sesame seeds, and sea tangle added yakkong cheonggukjang powder)	• Improved glycemic control (decreased supplementation of soybean cheonggukjang. Leptin and adiponectin levels were significantly decreased)	[99]
Cheonggukjang.	Diabetic	RCT, 3 arms	Adults with impaired fasting glucose (n = 30), 8 weeks Cheonggukjang (CH) vs. red ginseng Cheonggukjang (RGCH) vs. control group (starch), 20 g/day	• CH, RGCH group: decrease in fasting glucose level	[97]

Table 4. *Cont.*

Fermented Products	Functionality	Study Types	Consumption	Health Effects of Fermented Foods	References
Cheonggukjang.	Anti-allergy	RCT, placebo	Allergy adults with positive response from skin (n = 60), 12 weeks, 35 g/day	• Decrease in skin wheal response to histamine	[100]
Cheonggukjang	Skin	Open, controlled	Middle-aged women (n = 40) soybean diet and back massage (SDBM), 12 weeks, 35 g/day	• SDBM-group subjects had significant decrease in pH • Decrease in melanin and erythema indices	[101]
Soybean-based condiments	Diabetic	RCT	Hypertensive and type 2 diabetic (T2D) patients, Korean traditional-diet (KTD) group (n = 21), control group (n = 20), 12 weeks, 3 meal/day	• KTD (soybean-based condiments: 50 g/d): decrease in HbA1c (%), decrease in body fat mass, WC, BMI, and heart rate	[102]
Jeotgal	Anti-mutation	In vitro	Salted anchovies	• Salted anchovy fermented for 6 and 12 months showed anti-mutagenic activity	[103]
Jeotgal	Anti-oxidant	In vitro	Salted anchovies	• Salted anchovies contain phenolic compounds and proteins that exert significant antioxidant activity	[104]
Jeotgal	Anti-oxidant	In vitro	Yellow corvina jeotgal	• Improved scavenging activity due to Maillard reaction during fermentation	[105]
Jeotgal	Immune	In vivo	*Lactobacillus plantarum* isolated from salted fish	• Relieved ear edema • Decrease in serum Ig E levels • Increase in IFN-γ levels • Macrophage cell: increase in IL-12	[106]
Jeotgal	Cognitive	In vivo	Dementia-induced SD rats Squid (Todarodes pacificus) with 2–4% salt	• Boosted long-term memory activity • Improved acetylcholine levels in the brain	[107]
Jeotgal	Anti-obesity	In vivo	Obese mice: *Lactobacillus plantarum LG42 lactobacilli* isolated from flounder sikhae	• Decrease in body fat, serum TG, and insulin levels • Obesity gene: decrease in leptin and SREBP-1 • Liver: increase in PPARα and CPT-I mRNA	[108]
Jeotgal	Thrombosis	In vitro	*Bacillus velezensis* BS2 lactic acid bacteria isolated from salted seaweed	• Antithrombotic effect • Increased resistance to salt	[109]
Vinegar	Obesity/diabetic	In vivo	Persimmon vinegar	• Regulates body weight and blood glucose • Improves lipid metabolism by regulating TG, TC, and acid-insoluble acylcarnitine (AIAC)	[110]

Table 4. *Cont.*

Fermented Products	Functionality	Study Types	Consumption	Health Effects of Fermented Foods	References
Vinegar	Obesity	In vivo	Tomato vinegar	• Decrease in amount of visceral fat • Lowered the arteriosclerosis index • Increase in HDL-C/TC ratio	[111]
Vinegar	Hangover	In vivo	Cucumber vinegar	• Antioxidant activity: increase in DPPH and ABTS radical scavenging activity • Lowered levels of ammonia and lactic acid • Relieved hangover symptoms by increasing aldehyde dehydrogenase activity	[112]
Vinegar	Anti-fatigue	In vivo	Plum vinegar When the administration of plum vinegar and exercise were combined	• Decrease in lactic acid, ammonia, and inorganic phosphoric acid • Increase in endurance function	[113]
Vinegar	Anti-fatigue	In vivo	Persimmon vinegar	• Inhibited accumulation of lipids (TC, LDL-C, and TG) • Improved glycogen storage capacity (increase in muscle and liver glycogen content)	[114]
Vinegar	Anti-fatigue	In vivo	Cucumber vinegar In animals subjected to high-intensity exercise, the administration of cucumber vinegar	• Increased endurance by 56% and significantly reduced serum fatigue substances compared to the exercise-only group • Increased glycogen re-synthesis in the liver and muscles, and • increased LDH and creatine kinase in muscle tissue	[115]
Vinegar	Anti-fatigue	In vivo	Diet-induced obese mice: (tomato vinegar)	• Reduced ammonia, inorganic phosphates, and lactate in the blood • Increased LDH in muscles and maintained ATP in muscle cells	[116]

Abbreviation: ABTS, 2,2′-azino-bis-3-ethylbenzothiazoline-6-sul- phonic acid; ACC mRNA, Acetyl-CoA carboxylase mRNA; ACE, Angiotensin Convert Enzyme; AD, Atopic Dermatitis; AGTR2, Angiotensin II Receptor 2; AGTR2, Angiotensin II Receptor 2; AIAC, Acid-insoluble Acylcarnitine; AOM/DSS, Azoxymethane/Dextran sodium sulfate; Apo A1, Apolipoprotein A1; Apo B, Apolipoprotein B; BMI, Body Mass Index; CK, Creatine Kinase; CPT-I mRNA, Carnitine Palmitoyltransferase I mRNA; CRP, C-Reactive Protein; FPG, Fasting Blood Glucose; GSH, Glutathione Sulfhydryl; GSSG, glutathione disulfide; HMG CoA, 3-Hydroxy-3-Methyl Glutaryl Coenzyme A; IBS, Irritable Bowel Syndrome; IL-4, Interlukin-4; IL-6, Interlukin-6; IL-10, Interlukin-10; IL-12, Interlukin-12; IL-17a, Interlukin-17a; LDH, Lactic Dehydrogenase; MCP-1, Monocyte Chemoattractant Protein-1; MNNG, N-Methyl-N′-Nitro-N-Nitrosoguanidine; NK-cell, Natural Killing Cell; NO, Nitric Oxide; PPARα, Peroxisome Proliferator Activated Receptor α; DPPH, 2,2-diphenyl-1-picrylhydrazyl; RAS, Renin-Angiotensin System; RCT, Randomized Controlled Trial; SREBP-1, Sterol Regulatory Element Binding Protein; TBARS, TBA reactive substance; TLR4, Toll-Like Receptor 4; TNF-r, Tumor Necrosis Factor Gamma; TNF-α, Tumor Necrosis Factor –α; UCP-1, Uncoupling Protein-1; WC, Waist Circumference.

3.1. Hypertension

The high salt content of jang may constitute a health concern. However, previous research indicated a limited correlation between jang intake and hypertension [65,74]. Nonetheless, the duration of fermentation and salt content have an effect on blood pressure. In an animal model, mice treated with 8% common salt showed significantly higher blood pressure than those treated with 8% ganjang [65]. Thus, the effect of the salt in ganjang on sodium metabolism may differ compared to table salt. In another investigation, doenjang supplementation decreased blood pressure and controlled the renin–angiotensin system (RAS) better than general salt [73,74]. Specifically, doenjang with a longer fermentation duration was more effective in lowering blood pressure than doenjang with a shorter fermentation period. These findings can be attributed to the presence of arginine–proline, which inhibits RAS activity [117]. Furthermore, additional investigations are required to understand the effects of salt concentration in ganjang and doenjang on health. However, cheonggukjang appeared superior to boiled soybeans in regulating blood pressure as valine and tyrosine produced during fermentation inhibit angiotensin-converting enzyme (ACE) activity. In hypertensive rats, the administration of cheonggukjang effectively reduced blood pressure more than boiled soybeans [118]. Furthermore, the consumption of gochujang inhibited the ACE activity and suppressed thrombolysis and platelet aggregation [118]. Similarly, reports suggest that kimchi can alleviate blood pressure by increasing the inhibitory action of ACE [119]. Recently, the National Health and Nutrition Examination Survey (2007–2012) for Koreans showed a correlation between kimchi consumption and hypertension in Korean adults. In this survey, hypertension was low among those who regularly consumed kimchi [58]. However, due to the salt concentration in kimchi, a few investigations refute the positive impacts of kimchi on hypertension [59]. Hence, further investigations are necessary to understand the correlation between hypertension and kimchi consumption. Despite some contradictions, consumption of kimchi had much greater beneficial effects on MS-related blood pressure.

3.2. Obesity

The influence of kimchi on body weight depends on the degree of fermentation, and the ingredients used during preparation play a critical role in its beneficial effects. In an investigation on high-fat-diet-induced animals, kimchi inhibited the synthesis of adipocytes [120]. Additionally, kimchi containing red pepper revealed significantly reduced body weight and perinephric fat pads [120]. These results were due to capsaicin, an active compound in red pepper, and an accumulated metabolite during fermentation. Furthermore, capsaicin in red pepper powder stimulates the spinal nerves and secretion of catecholamine, promoting energy consumption and fat loss [120]. In a clinical investigation, the consumption of fermented kimchi by obese individuals suppressed the expression of obesity-related genes [51,52,54,121,122]. In addition, kimchi consumption significantly improved metabolic disease indexes, such as HDL-C, insulin, CRP, and blood pressure [51]. Furthermore, aged kimchi demonstrated a substantial effect on weight, BMI, blood pressure, body fat percent, fasting blood glucose, and TC than fresh kimchi [52,54]. Therefore, these observations confirm that thoroughly fermented kimchi has a greater beneficial effect on obesity, lipid metabolism, and inflammatory response than mildly fermented/fresh kimchi.

Doenjang potentially reduces risk factors associated with metabolic diseases, but the degree of protection depends on the fermentation time. Fermented doenjang promoted the β-oxidation process more than unfermented soybeans. Thus, it was more effective in decreasing visceral fat accumulation and increasing the lipid metabolism index than unfermented soybeans [76]. Clinically, the consumption of doenjang showed an extensive anti-obesity effect [77]. Here, the CT images clearly revealed that the consumption of 9.8 g of doenjang per day for 12 weeks reduced the visceral fat by 8.6 cm^2, which was about 8 times lower than that of the placebo group. In particular, the polymorphism of the obesity-related genes PPAR-γ2 [78] and UCP-1 [79] influenced lipogenesis. Additionally, in obese people with mutant alleles, doenjang intake was more efficient at lowering body fat. Therefore, it was suggested that a personalized diet needs to be based on the variations in the obesity gene.

Furthermore, the physiological activity of fermented gochujang against obesity was significantly higher than that of non-fermented gochujang and red pepper powder (capsaicin). Additionally, several reports indicate that the anti-obesity impact of traditionally prepared gochujang outweighs commercial gochujang. The activity against obesity could be due to the synergistic effect of the non-glycoside isoflavones of meju, the capsaicinoid component of red pepper, and metabolites produced during fermentation [123]. Capsaicin may have lowered body fat, while gochujang's secondary metabolites may have influenced energy and glucose metabolism. However, gochujang's additional components may have a significant role in obesity prevention [123,124]. Gochujang prepared with giant embryo rice koji showed a higher anti-obesity effect than the gochujang prepared with wheat *koji* [125,126]. Additionally, a gochujang with giant embryo rice Nuruk and soybean Nuruk showed greater anti-obesity effects than gochujang made with Tabasco hot sauce [127]. Hence, the ingredients used in making gochujang are crucial to its health benefits. A clinical trial revealed a lowered risk of cardiovascular disease when obese adults consumed 32 g of gochujang per day for 12 weeks. This treatment reduced the area of abdominal visceral fat and visceral, subcutaneous fat more than the placebo group [87]. A recent investigation demonstrated that the consumption of gochujang lowered visceral fat and improved the lipid profile [88]. Furthermore, the administration of cheonggukjang in obesity-induced animal models showed an anti-obesity effect and improved lipid metabolism [98,128–131]. Clinically, the consumption of cheonggukjang pills (about 35 g/day) for 12 weeks improved obesity and indexed lipid metabolism (Apo B) [96]. In particular, Apo A1, an index of lipid metabolism, increased in men and Apo B significantly decreased in women, confirming the improvement effect of arteriosclerosis indexes [96].

Persimmon vinegar is a representative fruit vinegar from Korea. It is rich in organic acids, such as acetic, citric, and malic acids, which effectively regulate weight and blood glucose levels. Additionally, persimmon vinegar improves lipid metabolism by regulating TG, TC, and acid-insoluble acylcarnitine (AIAC). The acetyl-CoA carboxylase (ACC) mRNA level was also lower in the persimmon fruit group, suggesting anti-obesity properties [110]. Moreover, tomato vinegar beverages reduced excessive fat accumulation in obese mice, as indicated by the increased HDL-C/TC ratio, decreased visceral fat content, and improved arteriosclerosis index [111].

Moreover, an investigation by Park and coworkers revealed *Lactobacillus plantarum* LG42 isolated from flatfish sikhae, a type of jeotgal (salted fish), confirmed to reduce body fat accumulation in obese mice. Furthermore, the levels of leptin and SREBP-1-related metabolic factors were decreased, while the mRNA expression of hepatic PPARα and CPT-I significantly increased in obese mice with *Lactobacillus plantarum* LG42 isolated from flatfish sikhae [108]. Additionally, *Bacillus velezensis* BS2 lactobacillus isolated from sea squirt jeotgal showed an anti-thrombotic effect and increased salt resistance [109]. Despite several preliminary investigations on salted seafood products associated with lactic acid bacteria, more large-scale studies are necessary to understand and confirm the beneficial effects.

3.3. Diabetes Mellitus

Lifestyle modifications are foremost used to reduce CVD risk factors. Healthy food consumption is one of the lifestyle modifications needed in order to have a healthy life. Active compounds and accumulated metabolites in kimchi positively affect overall human health and potentially helps to manage diabetes. The levels of pro-inflammatory cytokines (CRP, TNF-α, IL-6) associated with arteriosclerosis were significantly decreased upon the consumption of aged kimchi than fresh kimchi. In an animal model, the administration of kimchi for 4 weeks regulated the blood glucose levels in type 2 diabetes [52,132]. Then, gochujang (5% gochujang powder) supplementation to diabetic mice for eight weeks enhanced insulin sensitivity and blood glucose tolerance [90]. Furthermore, the use of gochujang by obese adults with mutations in the proliferator activator receptor-γ (PPARγ2) gene improved their insulin sensitivity and helped to regulate blood glucose levels [89].

Cheonggukjang is rich in dietary fiber and has a low-glycemic-index value, making it an excellent food for blood glucose management. Cheonggukjang effectively prevented diabetic complications, regulated enzymes associated with glucose metabolism in the liver, and increased insulin sensitivity in diabetic animal models [133–137]. The presence of trypsin inhibitor in cheonggukjang enhances insulin secretion and sensitivity, which helps to manage blood glucose levels. Clinically, the consumption of cheonggukjang for eight weeks significantly reduced fasting blood glucose (FBG), TC, and LDL-C levels [97]. Moreover, cheonggukjang improves insulin resistance by suppressing a-glucosidase activity in the small intestine [98]. In addition, cucumber vinegar has been demonstrated to have anti-diabetic effects via insulin regulation [138].

3.4. Regulation of Lipid Profile

Kimchi regulates risk factors associated with cardiovascular disease as it inhibits the production of lipids in blood vessels. The levels of pro-inflammatory cytokines (CRP, TNF-α, IL-6) associated with arteriosclerosis were significantly decreased upon consumption of aged kimchi than fresh kimchi [47,53,139]. Additionally, the consumption of aged kimchi (300 g/day) for 4 weeks significantly decreased body fat percent, blood pressure, fasting blood glucose, and TC than fresh kimchi (300 g/day), lowering risk factors linked to metabolic syndrome in obese individuals [52]. Furthermore, blood TG, LDL-C/HDL-C ratio, and arteriosclerosis index decreased in healthy adults consuming 30 g of cabbage kimchi (freeze-dried kimchi powder, 3 g/day) for 6 weeks [47]. Additionally, the intake of fermented kimchi (100 g per day) and fresh kimchi (100 g per day) in pre-diabetes showed different degrees of beneficial effects on obesity, lipid metabolism, and inflammation [53]. These different sorts of benefits with different types of kimchi indicate that degree of fermentation is key to health benefits.

Doenjang reduced the risk factors of arteriosclerosis and CVD by inhibiting the reduction and synthesis TC, VLDL-C, and LDL-C levels, as well as inhibition of lipid synthesis, thrombin production, and delayed fibrin coagulation [75,140]. The consumption of doenjang suppressed the development of thrombolysis and inhibited platelet aggregation [141]. Traditionally fermented gochujang has a higher impact than non-fermented gochujang on lipid metabolism. It is believed that capsaicin in gochujang positively affects energy and lipid metabolism by increasing catecholamine secretion from the adrenal medulla through the activation of the sympathetic nervous system. [142]. Clinically, gochujang intake effectively reduced obesity [143], hyperlipidemia [91], and blood TC and LDL-C levels. These findings suggest that the long-term intake of gochujang potentially prevents CVD risk factors. Protease, a proteolytic enzyme in cheonggukjang, suppressed cholesterol synthesis and showed an antithrombotic effect by reducing the inhibitory activity of HMG-CoA reductase in the body. In addition, cheonggukjang is rich in dietary fiber and indigestible saccharides, which help to prevent arteriosclerosis by reducing TG and TC absorption in the intestine and promoting lipid excretion through feces [144]. Clinically, cheonggukjang consumption exhibited an anti-arteriosclerosis effect on overweight and obese adults [145]. Moreover, cheonggukjang consumption reduced the ratio of Apolipoprotein B (Apo B) and ApoA1, an index protein associated with atherosclerosis.

3.5. Impact of Fermented Foods on Nutrients, Gut Microbiome, and Irritable Bowel Syndrome (IBS)

Microorganisms play a crucial role in the making of fermented foods. Microbes act on various biological materials that exhibit diverse biological effects. Kimchi has a sizable population of beneficial microorganisms that act as probiotics and improve intestinal health. The presence of lactic acid bacteria in kimchi that survive and reach the large intestine help to reduce intestinal pH, inhibit the growth of harmful bacteria, and inhibit the absorption of toxins in the intestine. The synergistic action of fiber and beneficial organisms is responsible for these unique effects. Irritable bowel syndrome (IBS) is a gastrointestinal disorder characterized by chronic abdominal pain and altered bowel movement without cause. In one of the clinical investigations, intake of kimchi by IBS patients for 12 weeks relieved IBS symptoms, such as abdominal pain, abdominal discomfort, decreased intestinal peristalsis, constipation, or abdominal distension. Moreover, it significantly reduced the level of TNF-α, one of the inflammatory cytokines that increase during IBS [55]. Similarly, the consumption of kimchi with dead nano-sized *Lactobacillus plantarum* nF1 for 12 weeks reduced serum inflammatory cytokines, harmful fecal enzyme activities, and promoted the growth of *Bifidobacterium adolescentis* in the gut [57]. Furthermore, the intake of 210 g of kimchi per day for four weeks in IBS patients is known to lower the pH, and concentrations of glucosidase and β-glucuronidase causing colon cancer. Moreover, the consumption of kimchi significantly improved lactic acid and Bifidobacterium bacterial populations, while harmful enzymes, such as β-glucosidase and β-glucuronidase, were significantly reduced [49]. Together, these observations showed that the consumption of kimchi benefits the intestinal environment and colon health.

Doenjang demonstrates several physiological functions due to fermentation-derived metabolites and soybeans. The major physiologically active substances in doenjang are phytoestrogen and 12 isoflavone isomers, including trypsin inhibitors, vitamin E, unsaturated fatty acids, daidzein, genistein, and glycitein [23,146]. Specifically, isoflavones are converted to aglycone forms, such as genistein, and daidzein, during the fermentation process of doenjang. Generally, vitamin K_2 and vitamin B_{12} are rarely present in soybeans. However, they are produced by microorganisms during fermentation. Moreover, the isoflavone content of cheonggukjang is approximately 21 times higher than that of boiled soybeans [147]. The absorption rate of isoflavones in boiled soybeans decreases when they are bound to sugar. However, during soybean fermentation, the enzymes that remove sugars change to genistein and daidzein, which increases digestion and absorption in the body, further enhancing physiological activity. Additionally, the consumption of cheonggukjang stew showed a higher absorption rate due to higher concentrations of isoflavone metabolites in the blood [90]. *Bacillus* sp. in Cheonggukjang enhances intestinal function, and insoluble dietary fiber shortens the colon transit time, improving overall intestinal health. In addition, there are about 100 billion germs per 100 g of cheonggukjang, which increases beneficial microorganisms in the intestine and eases intestinal movement [144,148]. Additionally, cheonggukjang promotes intestinal peristaltic motion and increases Bifidobacteria, which helps suppress the proliferation of harmful bacteria in the intestines [148]. Previous studies on cheonggukjang suggest that the regular consumption of cheonggukjang alleviates inflammatory colitis symptoms, such as weight loss, intestinal bleeding, and bowel abnormalities [149]. Together, these findings indicate the potential of cheonggukjang as a functional food.

Jeotgal is a low-calorie food, rich in essential amino acids, such as lysine and threonine, and has an umami taste due to presence of natural glutamic acid, alanine, and glycine [150]. The free amino acid content in jeotgal doubles after 72 days of fermentation. For instance, essential amino acids, such as lysine, glutamic acid, methionine, alanine, aspartic acid, and leucine, increase by about 1.3~5.8 times after 72 days of fermentation [103]. The fermentation process influences the conversion of phytochemicals into functional byproducts, improving jeotgal's health benefits. Recently, jeotgal has been identified as a distinct fermented food with exceptional health benefits.

3.6. Anticancer, Anti-Mutation, and Anti-Inflammation Properties of Fermented Foods

The consumption of kimchi showed antimutagenic and anticancer effects against known carcinogens, such as aflatoxin B_1 and N-Methyl-N′-Nitro-N-Nitrosoguanidine (MNNG). However, the fermentation method (temperature and duration) may have an impact on anticancer, anti-mutation, and anti-inflammation properties. It is reported that fermented kimchi has more pronounced anti-mutant effect than fresh kimchi [151]. Recent reports suggest that cancer-preventive kimchi (CPK) in animals induced with gastric cancer showed significantly lowered gastric mucosal ulcerations and erosive gastric lesions. Moreover, CPK reduced gastritis-linked inflammatory markers IL-1β, IL-6, and MMP-2, reducing the risk of gastric cancer and inflammation [152]. Thus, kimchi can aid in alleviating cancer symptoms. Specifically, fermented kimchi has a more robust, positive influence than raw or fresh kimchi. Additionally, fermentation byproducts, such as sulforaphane (cabbage), allicin (garlic), capsaicin (pepper), and gingerol (ginger), favorably interact with Nrf2, an antioxidant system in the human [153].

The anticancer activity of ganjang relies on several factors, including the type of ganjang, fermentation period, and the use of raw materials during preparation. Previous studies demonstrate the anticancer properties of ganjang against AOM/DSS-induced colitis-associated colon cancer (CAC) in a mice model [58]. However, acid-hydrolyzed ganjang showed little impact in suppressing colon cancer, whereas fermented ganjang significantly suppressed cancer. Furthermore, fermented ganjang with added sesame seeds (defatted sesame seed extracts) exhibited greater anticancer properties [58]. In addition, ganjang fermented with sesame seeds significantly reduced tumor necrosis factor-α (TNF-a) and inflammatory cytokines (IL-6, IL-17-α) compared to acid-hydrolyzed ganjang [67]. Specifically, ganjang fermented with sesame seeds significantly increased the expression of colonic p53, a tumor suppressor gene indicating stronger anticancer effects [67]. Interestingly, ganjang aged more than 15 years significantly increased spleen cell proliferation and NK-cell activity compared to ganjang aged less than 15 years [154]. Moreover, the administration of soy sauce-derived polysaccharides demonstrated enhanced proliferative activity of bone marrow cells, antioxidant activities, and anti-inflammatory activities in rats [149]. Recently, in animals induced with colorectal cancer, the administration of ganjang made with bay salt significantly increased apoptosis and had a greater inhibitory effect on colon cancer than ganjang made with refined salt [155]. Collectively, these observations clearly suggest the anticancer activity of ganjang.

Meju, a raw material used for doenjang, is highly susceptibility to aflatoxin-producing fungi. Chronic exposure to aflatoxin increases the risk of cancer. However, the fermentation period determines the production of aflatoxins. The presence of microorganisms in doenjang aged for more than a year delayed/restricted the aflatoxin production [156]. Interestingly, the anticancer and antimetastasis activities of doenjang are high due to the extended fermentation period [157]. In an animal model, the inhibition rate of cancer cells was observed to be 19% in doenjang prepared after 6 months of fermentation, while it was 38% in 2-year-old doenjang. The lung anti-metastasis effect was 72% for 6-month fermented doenjang and 82% for 24-month fermented doenjang [72]. Doenjang has been shown to have liver detoxification and tumor suppression effects. In particular, doenjang administration in animals induced with rectal cancer increased the level of immune-related cytokines. Additionally, doenjang administration significantly inhibited the activity of various human-derived cancer cells (liver, breast, prostate, lung, stomach, and colon cancers). Moreover, doenjang is effective in anti-cancer activity by reducing oxidative stress and significantly increasing NK-cell activity linked to cancer cell removal [158–167].

The anticancer and tumor metastasis inhibitory effects of gochujang depend on the preparation method. It is widely accepted that the longer the fermentation period, the stronger the anticancer effects. Thus, traditional gochujang has stronger anticancer properties than commercial gochujang. Gochujang treatment strongly inhibited cancer cell growth in most cancer cells, including gastric, colorectal, lung, cervical, and liver cancers [85,168,169]. As expected, traditional gochujang fermented for 6 months showed stronger anticancer effects than commercially fermented and non-fermented gochujang [170,171]. The fermentation of jeotgal uses a high concentration of salt (20~30%), and the bay salt used for jeotgal exhibits mutagenic activity when present with carcinogens. Unfermented jeotgal can present mutagenic activity due to high concentrations of salt, but fermented anchovy jeotgal has anti-mutagenic activity [104]. Anchovy jeotgal is one of the important ingredients of kimchi. The anti-mutant effect of anchovy jeotgal is significantly different depending on the fermentation period. Generally, anchovy is the main raw material used for jeotgal. Previous investigations on fermented pickled anchovy indicated preventive effects on somatic mutation, while fresh, salted anchovies showed antimutagenic effects in a Drosophila model. Jeotgal made with anchovies aged 6 and 12 months showed 26.6% and 43.4% of antimutant activity, respectively [103]. Salted, raw anchovies can cause mutations, but fermented, salted fish significantly increase the anti-mutant effect, demonstrating the significance of fermentation. The consumption of salted fish is known to have a hepatocellular antitumor effect, and the effect is superior in traditional jeotgal than that of commercial jeotgal [172]. Compared to commercial jeotgal, sikhae showed a higher cell survival rate of about 77.6% in HepG2 cells. That is, the physiological activity was significantly observed in the order of flatfish jeotgal, squid jeotgal, and small squid jeotgal. The antitumor effects of sikhae differ depending on the ingredients employed in its production. The presence of physiologically active grains, garlic, and red pepper in the final product are thought to be responsible for the antitumor activity [172,173]. Additionally, proteins isolated from salted anchovy showed significant anticancer activity in cancer cells (K-562). In animal models, the administration of jeotgal from anchovy increased phagocytic and NK-cell activities, indicating an immune-enhancing effect. Additionally, isolated lactic acid bacteria demonstrated strong α-fibrinogenase activity and moderate β-fibrinogenase activity [174]. Interestingly, the isoflavone content of cheonggukjang is about twice that of steamed soybeans [147], and the antioxidant action was proportional to polyphenol and isoflavone contents [142]. Fermentation produces free amino acids, peptides, and phenolic acid, influencing antioxidant activity. Thus, the consumption of cheonggukjang shows high antioxidant activity compared to steamed soybeans. Specifically, Genistein, an isoflavone in cheonggukjang, inhibits superoxide anion formation and removes hydrogen peroxide, improving antioxidant and lipid peroxidation [174]. Generally, phenolic compounds found in fruits and vegetables exert antioxidant effects. Animal-based phenolic compounds are rare, but salted anchovies contain phenolic compounds and proteins that exert significant antioxidant activity [104]. Additionally, glutamic acid and lysine in salted fish showed strong anticancer activity than the fermented soy products. In Korea, yellow Corvina is widely used as compensatory raw material for jeotgal, which has improved scavenging activity due to the Maillard reaction during fermentation [105]. Furthermore, anchovy jeotgal contains large quantities of amino acids, such as threonine, glutamic acid, lysine, serine, and proline, which are present as ACE inhibitors and regulate blood pressure [175].

3.7. Influence of Fermented Foods on Immunity, Immune Respose, and Allergic Response

It is easy to acquire colds, chronic fatigue, and infectious diseases if immunity declines. According to the Korea National Health and Nutrition Examination Survey (2007–2011), the prevalence of asthma in adults who consumed more than 40 g of Kimchi per day was lower than the adults who consumed less than 40 g of kimchi per day [60]. In addition, the correlation between kimchi intake and atopic dermatitis was confirmed in Korean adults aged 19–49 years [61]. Additionally, individuals who consumed 85~160 g of kimchi per day had a 0.68 times lower risk of developing atopic dermatitis than those who consumed only 0~36 g. In addition, the prevalence of allergic rhinitis decreased by 0.81 times in individuals who consumed 108~180 g of kimchi per day compared to those who consumed 0~23.7 g per day [62]. These observations strongly suggest that an increase in kimchi consumption is directly associated with a reduction in the severity of atopic dermatitis, asthma, and rhinitis. In addition, the consumption of doenjang is believed to enhance immunity. Surfactin derived from Bacillus subtilis in doenjang has been has been proved to be effective against influenza and Ebola [176]. This effect is a result of the Bowman Buck Inhibitor (BBI), a serine protease inhibitor found in soybeans, which inhibits virus penetration by degrading cell membranes. Furthermore, when doenjang was administered to high-fat diet animals; oxidative stress indexes and inflammatory-related cytokines decreased significantly, demonstrating anti-inflammatory and antioxidant activity [80,177–179]. Moreover, traditional doenjang contains immunomodulatory substances (KFSPs), which are not found in steamed soybeans [180]. According to previous reports, KFSPs have a beneficial effect on immune regulative action by enhancing the activities of cytokines [180,181].

Cheonggukjang contains a considerable amount of gamma-PGA (γ-PGA), a polymer compound produced by a lactic acid bacteria, Bacillus subtilis, which exhibits immunomodulatory properties and promotes immunological function. Additionally, γ-PGA stimulates IFN-gamma and TLR4 (Toll-like receptor 4) secretion, which improves NK-cell activity, leading to collective improvements in the immune system [181–183]. Cheonggukjang helps to improve allergies (atopic dermatitis) caused by immune sensitivity [100,184]. In an atopic dermatitis animal model, the administration of cheonggukjang suppressed the expressions of serum Ig E, Th_2 cytokine IL-4, and itching-related IL-31 cytokines [184] that appeared during an excessive immune response. Moreover, cheonggukjang pills (27 g/d of fresh cheonggukjang) taken for 12 weeks significantly alleviated allergic reactions to histamine [100].

Lactobacillus plantarum isolated from jeotgal exhibited broader-ranging anti-allergic effects. Previous reports indicated that the administration of lactic acid bacteria isolated from jeotgal alleviated ear edema and lowered serum Ig E levels in animal models [106]. In addition, lactic acid bacteria from jeotgal exhibited anti-inflammatory effects on atopic dermatitis by increasing IFN-γ production in CD4+T cells and increased IL-12 levels in macrophages.

3.8. Influence of Fermented Foods on Oxidative Stress, Aging, and Memory Function

Oxidative stress is the cause of several diseases, including metabolic diseases, diabetes, dementia, and cancer. Kimchi contains antioxidant compounds (vitamins C and A), lactic acid bacteria, and accumulated metabolites that assist in removing free radicals. The degree of fermentation is presumed to affect the efficacy of kimchi as an antioxidant. Generally, aged kimchi had a greater antioxidant effect than fresh kimchi [185]. The administration of kimchi made with 30% mustard leaf showed anti-aging effects by suppressing the production of free radicals and increasing antioxidant enzyme activity in mice brain [64]. This effect represented that cabbage kimchi made by adding 30% of mustard leaves suppressed much more free radical production in the brain than standard kimchi. Moreover, in an animal model of Alzheimer's disease, the administration of kimchi for 2 weeks considerably enhanced the objective cognitive ability [186]. Additionally, the administration of kimchi suppressed the deterioration of the cranial nerve function induced by Aβ-25–35 and lipid peroxidation in the mice brain [186]. Thus, kimchi is expected to play an important role in preventing aging-related dementia and chronic diseases in the brain.

Cheonggukjang contains large amounts of isoflavone, glycans, peptides, dietary fiber, γ-PGA, and microorganisms, which can control inflammation and oxidative stress better than other soybean-fermented foods. Cheonggukjang has high levels of γ-PGA, which enhances the brain's insulin sensitivity and improves memory [187]. In addition, cheonggukjang is known to relieve memory impairment induced by Alzheimer's disease and cerebral ischemia by modulating the gut–microbiome–brain axis. In aging-induced animal models, the administration of doenjang helped to protect the brain nerves by regulating gene expression in the production and degradation of amyloid beta in the brain and reducing levels of β-amyloid peptide (Aβ). In particular, doenjang had a greater inhibitory effect on brain neurodegeneration than steamed soybeans [81]. These observations clearly suggest that the consumption of doenjang enhanced brain neuroprotective effects through physiologically active compounds produced during fermentation. Furthermore, jeotgal was observed to improve cognitive function. Jeotgal prepared with Japanese squid (*Todarodes pacificus*) with 2–4% salt indicated to have improved cognitive function in dementia-induced SD rats [107]. In this study, jeotgal made with Japanese squid reduced memory degeneration, boosted long-term memory activity, and greatly improved acetylcholine levels in the brain. However, more clinical studies need to be done to understand jeotgal's functional relevance in terms of cognitive function.

3.9. Anti-Fatigue and Hangover Relief by Fermented Foods

In Korea, plums are believed to have gastrointestinal functions, such as fatigue recovery, digestion, vomiting, and constipation. Plum vinegar is rich in organic acids, such as citric and malic acids, which play key roles in regulating fatigue-related symptoms. Additionally, levels of fatigue-related substances, such as lactic acid, ammonia, and inorganic phosphoric acid, were significantly lowered in mice blood upon supplementation with plum vinegar. Additionally, phenolic acids, such as protocatechuic, syringic, and chlorogenic acids, relieved fatigue symptoms [113]. The intake of persimmon vinegar suppressed the accumulation of lipids (TC, LDL-C, TG) and was shown to improve the glycogen storage capacity (increasing muscle and liver glycogen content), which helped to improve stamina during exercise [114]. In animals subjected to high-intensity exercise, the administration of cucumber vinegar increased endurance by 56% and significantly decreased the concentration of serum fatigue substances compared to the exercise-only group [115]. That is, the intake of cucumber vinegar increased glycogen resynthesis in the liver and muscles, and increased LDH and CK in muscle tissues. Moreover, tomato vinegar beverages reduce ammonia, inorganic phosphate, and lactic acid in the blood, indicating its beneficial effects on fatigue substances [115,116]. Vinegar made with Salicornia herbacea removed DPPH and ABTS radicals, demonstrating its antioxidant properties. Interestingly, it prevented fatigue by reducing the concentration of ammonia, inorganic phosphates, and lactate in the blood, by increasing muscle LDH, and by maintaining ATP in muscle cells [112]. In particular, cucumber vinegar drinks significantly increased antioxidant activity by increasing DPPH and ABTS radical elimination activities and reducing the fatigue substances, such as ammonia and lactic acid in the blood [112,138]. In addition, vinegar relieves hangover symptoms by reducing the concentration of acetaldehyde in the blood and increasing aldehyde dehydrogenase activity in mice liver. Thus, consuming vinegar enhances the taste of food while providing health advantages thereafter.

4. Conclusions and Future Approach

Traditional fermented foods have a long-standing relationship with the region, season, and availability. There are several fermented foods worldwide, and the characteristics of traditional fermented foods vary according to geography and the availability of raw materials in the specific region. With the introduction of salting into Korean cuisine, salted and fermented foods dominate the Korean diet. With time, the salting process dominated food preparation and led to the development of several fermented foods. Since then, Korean foods that best reflect the traditional fermentation process include kimchi (fermented vegetables), jang (fermented soybean products), jeotgal (salted fermented fish), and vinegar. Over the past decade, extensive research has been conducted to verify the health benefits of fermented foods. Additionally, modern science and technology have been adapted to increase the production of fermented foods while preserving traditional fermented food characteristics. Thus, expanding production may facilitate the global reach of fermented foods and accelerate therapeutic research. With a global presence, sharing information and experiences can assist innovations in fermented food preparation, mass production, and clinical research. Hence, given the traditional, functional, and historical importance of fermented foods, our responsibility is to continue the legacy of fermented foods.

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