Journal of Ethnic Foods

REVIEW ARTICLE Open Access

Scientific knowledge and wisdom of kimchi: a blessing Korean

Dae Young Kwon[1,2*], Kyung Rhan Chung[2], Chang Hyeon Lee[3], Soon-Hee Kim[2], James W. Daily[4] and Sunmin Park[5]

Abstract

Kimchi, a unique traditional fermented food of Korea, is a product of agricultural necessity and scientific serendipity. This blessed food, born from the efforts of Korean women striving to create delicious and lasting sustenance, has become an integral part of Korean cuisine. Always present in the traditional Korean bapsang, which means meal table setting alongside bap (rice), kuk (soup), and banchan (side dishes), kimchi's appeal remains constant despite frequent consumption. The origin and evolution of kimchi are intrinsically linked to Korea's history, with fermentation techniques and ingredients adapting to diverse regional and social environments over time. While contemporary research often focuses on kimchi processing and its health benefits, fewer studies explore the fermentation mechanisms, historical background, safety aspects, and preservation techniques of kimchi. Understanding the nature of kimchi requires a comprehensive examination of its biological role and historical context. This manuscript reviews kimchi fermentation from scientific and cultural perspectives, covering ingredients, microorganisms, fermentation mechanisms, and preservation history. We also discuss the safety, palatability, and health benefits of kimchi. The development of kimchi reflects centuries of culinary innovation by Korean women, who created yangnyom (seasonings) and fermented foods to enhance the nutritional value and flavor of bap, ultimately shaping the unique and delightful Korean cuisine we know today.

Keywords Kimchi, Birth history, Serendipity, Vegetable fermentation, Banchan

Introduction

Kimchi, a traditional Korean fermented food, has gained global recognition for its unique organoleptic properties, nutritional value, and health benefits. This iconic dish is prepared using various vegetables such as cabbage, radish, and cucumber, fermented by lactic acid bacteria [1, 2]. The cultural significance of kimchi is deeply rooted in the Korean approach to cuisine, which emphasizes the art of complementing bap (rice) with banchan (side dishes), in contrast to Western culinary traditions that focus primarily on main courses. The traditional Korean table setting, known as bapsang, reflects this philosophy. It typically features rice on the left, kuk (soup) on the right, accompanied by jang (fermented soy sauces), and an array of banchan [3]. This arrangement stems from the perpetual quest of Korean ancestors to enhance the enjoyment of rice, creating dishes that remain appealing even with frequent consumption [2].

Geographical and agricultural factors unique to Korea shaped the development of its cuisine. Unlike China or Western countries, Korea's resources were primarily vegetables and seasoning ingredients such as peppers, garlic,

*Correspondence:
Dae Young Kwon
dykwon53@gmail.com
[1] Hoseo University, Asan 314900, Choongchung Nam-do, Korea
[2] Institute of Food Culture and Science, # 1109, Ace-Dongbaek Tower, 16-4 Dongbaek-Joongang Blv 16th, Kiheung-ku, Yongin, Kyongki-do 17015, Republic of Korea
[3] World Institute of Kimchi, Nam-ku, Kwangju 61755, Korea
[4] Department of R&D, Daily Manufacturing, Rockwell, NC, USA
[5] Hoseo University, Asan, Choongchung Nam-do, Korea

scallions, ginger, and soybeans. These ingredients formed the basis for yangnyom, Korea's distinctive seasoning blends, and jang, fermented soy sauces. Combining these elements gave rise to the diverse and flavorful banchan that characterize Korean cuisine [3–5]. The evolution of Korean food culture led to the creation of two broad categories of banchan: non-nutrient foods for everyday consumption and nutrient-rich "dishes" reserved for special occasions [2]. The seasoning of banchan with jang and yangnyom [2, 6] represents a unique aspect of Korean culinary tradition. This "yangnyom culture" [7] not only enhanced the flavor of vegetables but also significantly improved the overall dining experience, particularly in complementing rice.

Kimchi emerged as a natural extension of this yangnyom culture, representing a serendipitous discovery that addressed both the desire for flavorful food and the need for long-term preservation. The fermentation process, facilitated by lactic acid bacteria, not only enhanced taste but also solved the challenge of food storage [2, 7]. While contemporary research often focuses on kimchi manufacturing processes and its health benefits [8], there is a notable gap in studies exploring the fundamental mechanisms of kimchi fermentation, its historical background, and the reasons behind its safety, palatability, and long shelf life. Understanding these aspects is crucial to fully appreciate the nature of kimchi and its role in Korean culture and cuisine.

This paper aims to delve into the science behind kimchi production, exploring how microorganisms contribute to fermentation, and examining why kimchi remains delicious and digestible even with frequent consumption. We will discuss the health benefits of kimchi and investigate the ancestral wisdom that contributed to its development. By combining scientific knowledge with historical insights, we seek to provide a comprehensive understanding of kimchi as both a culinary staple and a cultural phenomenon.

Scientific knowledge of kimchi fermentation

Making kimchi, kimjang and kimchi fermentation

Traditionally in Korea, kimchi was made from Spring to Autumn with the vegetables from the individual backyard garden with yangnyom, however, in late Autumn large quantities of kimchi are prepared as an annual event, for eating during the winter when the fresh vegetable supply is limited. We called this 'kimjang culture' [9]. Most of the vegetables cultivated in Korea are used as sources for making kimchi. Almost two hundred kinds of kimchi are currently reported, depending on the varieties and preparation methods of those vegetables [1, 10].

Kimchi was typically prepared with Chinese cabbage, the major vegetable: cabbage is trimmed to small pieces and thoroughly washed. The excess water is drained and brining takes place. During brining, a proper amount of table salt is added and left for 2–3 h to maintain hypertonic shrinkage. In a hypertonic state, the growth of microorganisms, especially harmful bacteria is inhibited. It is known that capsaicin in chili killed other microorganisms than lactic acid bacteria and rather promoted the growth of lactic acid bacteria [11]. Meanwhile washing, cutting, and mixing spicy raw materials such as kochu (chili), green onion, garlic, ginger, and so on, takes place for making yangnyom. When the brining is completed, the excess water is drained again, and yangnyom from all the raw materials is mixed [1, 10]. Fermentation conditions depend upon consumers's taste and storage needs; short-term consumption requires fermentation at room temperature in Summer whereas longer storage times require fermentation at low temperatures in Winter. The product can be called kimchi only after the completion of the fermentation process [12, 13].

During the storage of kimchi, fermentation by lactic acid bacteria takes place with the help of the capsaicin from kochu (chili) for producing lactic acids and many metabolites [10, 14]. Kimchi fermentation may be divided into four stages based on the acidity produced [15]: (1) the initial stage with acidity < 0.2%, (2) the immature stage with acidity between 0.2 and 0.4%, (3) the optimum-ripening stage with acidity between 0.4 and 0.9%, and (4) over-ripening or rancid stage with acidity > 0.9%. The dominating lactic acid bacteria are responsible for the production of acidity, through the fermentation of the available carbohydrates. The type and quality of the raw materials, as well as fermentation conditions decisively affect the course of fermentation. During the kimchi fermentation process, microecosystems such as temperature, acidity, and redox potential (oxygen content) in kimchi changed. In other words, the microbiota during kimchi fermentation was changed according to temperature, acidity, and amount of oxygen [16].

Kimchi fermentation stage and changes in lactic acid bacteria

The fermentation stages of kimchi can be divided into the immature stage, rapid fermentation stage, stationary ripe stage, over-ripe stage, and spoilage stage based on acidity, lactic acid bacteria count, and other factors [17, 18]. During the immature stage, bacterial growth is suppressed, and a nutritionally favorable environment for hetero-lactic fermentation bacteria such as *Lactobacillus* spp., *Leuconostoc* spp., and *Weissella* spp. is established under anaerobic conditions [14]. This marks the beginning of lactic acid fermentation in earnest. The taste during this stage is mild, with the natural flavors of the kimchi ingredients being prominent (acidity below

0.3%). The ripe stage signifies the onset of the matured taste characteristic of kimchi, with a rapid increase in the population of lactic acid bacteria, resulting in the best flavor profile (acidity between 0.3 and 0.8%). The over-ripe stage occurs when the acidity reaches its maximum level, resulting in a strong sour taste. While initial lactic acid bacteria such as those from *Lactobacillus* spp., *Leuconostoc* spp., and *Weissella* spp. decrease, species like *Lactobacillus plantarum* and *Pediococcus cerevisiae* increase, leading to a loss of the refreshing and clean taste of kimchi, becoming excessively sour (acidity above 1.0%) [17, 18].

The spoilage stage begins when the proliferation of lactic acid bacteria ceases, and they start to decline. When kimchi becomes sour, yeast species (Candida, Pediococcus, Saccharomyces spp., etc.) that can grow in acid begins to grow on the surface of kimchi to form a film. In this way, the white colony-forming yeast or white acid membranes on the surface of kimchi are called *'golmaji'* [19]. When *golmaji* occurs, lactic acid fermentation no longer occurs, and various reactions take place and deteriorate, causing various smells such as gangsta, it is softened due to becoming fizzy and losing its crispness, and can no longer be eaten. The main yeast that causes *golmaji* is *Pichia kudriavzevii*, and others such as *Hanseniaspra uvarum, Pichia kluyveri, Yarrowia lipolytica, Kazachstania servazzii,* and *Candida sake* were identified [19, 20].

Fermentation microorganisms

Most of the microorganisms involved in the fermentation of kimchi are referred to as lactic acid bacteria because they produce lactic acid [21, 22]. Lactic acid bacteria are bacteria that perform lactic acid fermentation based on their metabolic characteristics, and they are classified into homo-fermentative lactic acid bacteria, which primarily produce lactic acid using glucose, and hetero-fermentative lactic acid bacteria produce lactic acid but also produce acetic acid, carbon dioxide, ethanol, etc. The types and distribution of lactic acid bacteria involved in kimchi fermentation are significantly influenced by the factors including ingredients, salt content, and fermentation temperature. However, lactic acid bacteria belonging to genera such as *Lactobacillus, Leuconostoc*, and *Weissella* are the main fermenting microorganisms [14, 23]. These bacteria are facultative, meaning they can grow well under both anaerobic and aerobic conditions and produce lactic acid. During the fermentation process of kimchi, lactic acid bacteria produce different fermentation by-products depending on their species and fermentation conditions, thereby determining the taste and quality of kimchi [24]. In most cases, these lactic acid bacteria ferment from the main and secondary ingredients of kimchi, such as cabbage, garlic, ginger, and chili powder. Lactic acid bacteria directly affect kimchi fermentation, and bacteria such as *Weissella, Leuconostoc*, and *Lactobacillus*, are known to originate from garlic and cabbage. They produce fermentation metabolites that enhance the taste of kimchi. While relatively few lactic acid bacteria emerge from chili powder, capsaicin found in chili powder inhibits the growth of other unwanted microorganisms and promotes the growth of lactic acid bacteria [11].

Ingredients of kimchi

As mentioned earlier in this paper, the core ingredients of kimchi fermentation are not cabbage and radish but chilies (in the form of chili powder) [7]. Chili powder is a crucial food ingredient that provides the red color and spiciness to kimchi. Among hundreds of kinds of chili, the chili peppers used in kimchi are Korean varieties (kochu, *Capsicum annuum*) that have been grown on the Korean Peninsula for tens of thousands of years [25]. It is because of these kochu peppers that kimchi was discovered. Even today, kimchi cannot be made or consumed with wild-type peppers from Central and South America or even India. The main components of chili peppers are anthocyanin, which gives color, capsaicin, which provides spiciness, and vitamin C. A Hungarian scientist first discovered vitamin C in chili peppers [26]. Although dry chili powder is commonly used in kimchi, in some regions of Korea, fresh peppers are ground and used. Phytochemicals like capsaicin in chili peppers inhibit the growth of spoilage bacteria during kimchi making and create an environment conducive to the growth of lactic acid bacteria [11]. The scientific evidence of the diversity of chili peppers and the presence of our unique Korean peppers in Korea for a long time is elaborately discussed in a previous paper [7].

Garlic plays a significant role in the fermentation of kimchi. Garlic contains compounds like allicin that have antioxidant properties and contribute to kimchi's delicious flavor. According to a paper published by the World Kimchi Research Institute, lactic acid bacteria such as *Leuconostoc* and *Weissella*, which have a direct impact on kimchi fermentation, originate from garlic [27]. Additionally, garlic delays microbial growth and controls the appearance of lactic acid bacteria during fermentation, extending the fermentation period of kimchi and enhancing its storage properties.

Ginger complements vegetables without flavor (cabbage and raddish) with its unique strong aroma and spiciness. Ginger has long been used as both a key ingredient in traditional Korean medicine and a core ingredient in food ingredients such as kimchi seasoning. Ginger's spiciness is composed of the essential oils 6-gingerol and 6-shogaol. When ginger is added to

kimchi, it helps the growth of *Leuconostoc mesenteroides*, lactic acid bacteria, that occur during fermentation [28].

Salt is used to flavor vegetables before mixing them with kimchi yangnyom, except for *'geotjeori'*. When cabbage is salted, the osmotic pressure reduces the cells of the vegetables and ordinary bacteria cells to a hypertonic state, causing water to be expelled, reducing volume, and making it soft and flavorful. It also inhibits the activity of bacteria. Simultaneously, adding salt to kimchi yangnyom enhances the flavor balance. Salt used in making kimchi prevents the growth of harmful microorganisms during storage and assists in lactic acid fermentation. Traditionally, Korea used sun-dried sea salt when making kimchi. Using sun-ripened sea salt aged for 2–3 years helps maintain the properties of kimchi. To make kimchi with a proper texture and store it for a long time, it is advisable to remove minerals such as magnesium chloride and magnesium sulfate during the aging process because they give a bitter taste. Aside from using salt to flavor, kimchi can also be flavored with long-fermented traditional soy sauce (kanjang) [6]. Flavoring with kanjang produces a unique and deep taste compared to when salt is used alone.

Kimchi is mainly made using cabbage. There are various types of cabbage and different types are planted depending on the season—Spring cabbage in Spring, *olgari* cabbage and *altari* radish in Spring and Summer, and kimjang cabbage in fall. Cabbage, especially the kimjang cabbage, with its large, crunchy stems, is one of the most suitable vegetables for salting and seasoning for kimchi preparation. Cabbage, a member of the cruciferous vegetable family, contains antioxidants and antimicrobial substances such as sulforaphane. Refuting baseless claims that cabbage (specifically the napa cabbage) was introduced very recently (less than 100 years ago), previous historical documents and scientific papers provide convincing evidence of a long history of cabbage as a kimchi ingredient [7, 29].

Radish is the second most commonly used ingredient in kimchi and is the main ingredient in *dongchimi* and *kakduki* (please recommend the figures in other Korean kimchi books) (Fig. 1). Radishes are rich in various digestive enzymes and provide several times more vitamin C than apples [30], making them a valuable ingredient for supplying vitamins during the Winter when vitamin deficiencies are common. The starches, such as glucose, contained in radishes are utilized as food for the lactic acid bacteria in kimchi, helping to ferment the kimchi well. Moreover, radishes are rich in amylase, diastase, and other digestive enzymes, making radish kimchi (*dongchimi*) useful as a digestive aid since ancient times.

Jeotgal (fermented seafood products) like anchovies and shrimp, salted and fermented, are also used as kimchi seasoning [31]. In addition to salt and soy sauce, adding *jeotgal* enhances the flavor of kimchi. *Jeotgal*, already fermented, enhances the richness and aroma of kimchi when added. *Jeotgal* can be divided into solid fermented seafood (*saengjeot*) and liquid-filtered fish sauce (*actjeot*). *Jeotgal* acts as a source of protein for lactic acid bacteria during kimchi fermentation, increasing the essential amino acid content and promoting kimchi fermentation.

Types of kimchi

The essential components of kimchi fermentation are derived from Yangnyom (seasoning) ingredients. In other words, the core ingredients of kimchi—such as chili peppers, garlic, scallions, ginger, and salt—are used to make various vegetables tasty. Cabbage and radish are the primary vegetables, but other vegetables like green onion and mustard leaf are also common. Therefore, by changing the main vegetables, hundreds of different types of kimchi can be created. This illustrates how early Koreans found ways to make various types of vegetables tasty.

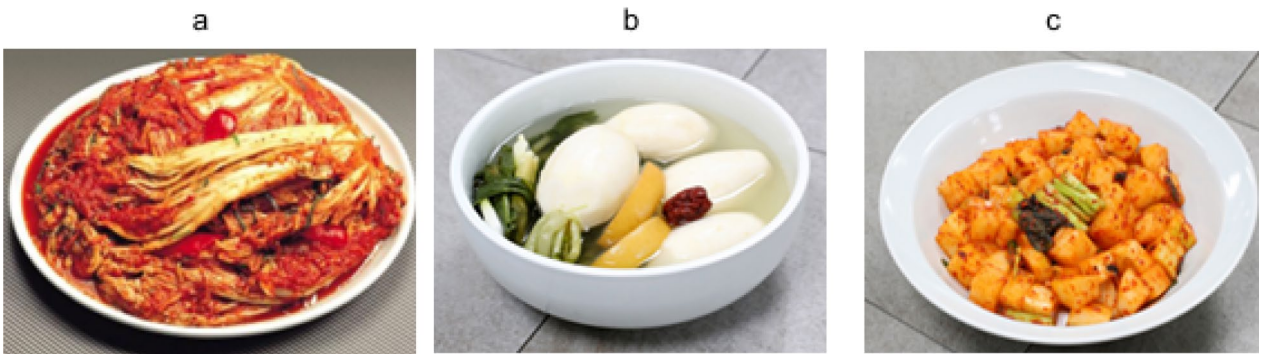

Fig. 1 Classification of traditional Korean kimchi by seasonal preparation. **a** Cabbage kimchi, **b** Radish-based kimchi varieties including dongchimi and sinkeonji, and **c** kakdugi (radish kimchi). Kimchi varieties shown can be categorized as kimjang kimchi, traditionally prepared in late autumn for winter consumption. Images of dongchimi and kakdugi courtesy of the World Institute of Kimchi (Gwangju, Korea)

Korea is characterized by high mountain ranges in the northeast and plains along rivers in the southwest, surrounded by sea on three sides, resulting in a blend of continental and maritime climates with distinct seasons. Influenced by this terrain and climate, each region in Korea has its unique kimchi cuisine culture. Consequently, the types of kimchi vary by region and season, resulting in hundreds of variations. Kimchi, specially made to preserve seasonal vegetables, varies widely in ingredients and preparation methods according to the local social and cultural environment. Kimchi types can be broadly categorized into kimjang kimchi such as cabbage kimchi, *dongchimi*, and radish kimchi (Fig. 1), and seasonal kimchi such as Spring bronze kimchi, *Olgari* cabbage kimchi, *yolmu* kimchi, *altari* radish kimchi and kat (mustard leaf) kimchi (Fig. 2), which are easily made and eaten as banchan, with hundreds of variations based on the main seasoning ingredients and vegetables.

Historical records also demonstrate the diversity of kimchi. Various documents [7] such as s "Tomudaejak (屠門大爵)" (1611) by Heo Gyun, "Sallimkyongje (山林經濟)" (by Hong Man-sun (1643–1715), "Jeungbo-sallimkyongje (增補山林經濟)" (1766) by Yu Jeung-rim's and "Eumsikdimibang" in seventeenth century record diverse types of kimchi, including pak kimchi (gourd kimchi), bamboo shoot kimchi, and mustard leaf kimchi. These records show that not only cabbage kimchi but also various types of kimchi based on different vegetables, yangnyom (seasonings ingredients), meat, fermented fish or grains, and variations according to seasons and regions have existed for a long time.

Scientific wisdoms of kimchi

What do lactic acid bacteria feed in vegetables?

Despite vegetables like cabbage having low sugar contents, including other types of sugars, lactic acid bacteria still thrive during kimchi fermentation. Unlike grapes in wine production that contain sugars broken down by amylase into alcohol, or milk in cheese and yogurt fermentation rich in lactose for lactic acid bacteria growth, the situation in kimchi fermentation differs due to the absence of abundant sugars in vegetables and the lack of cellulase enzymes produced by kimchi lactic acid bacteria.

This unique aspect of kimchi fermentation is what sets it apart from other fermented foods. While grapes and milk contain readily available sugars for fermentation, vegetables used in kimchi have limited sugar

Fig. 2 Representative seasonal kimchi varieties prepared in spring and summer. Featured varieties include cabbage olgari, yeolmu radish kimchi, altari radish kimchi, and mustard leaf (kat) kimchi. Each variety possesses distinctive flavor profiles and taste characteristics. The Dolsan island region of southern Korea is particularly renowned for its mustard leaf kimchi. Images of kat kimchi and kakdugi kimchi courtesy of the World Institute of Kimchi (Gwangju, Korea).

content, making it challenging for lactic acid bacteria to thrive solely on sugars. To compensate for this, various methods are employed. In Spring and Fall, when vegetable sugar content is low, glues from rice or wheat are sometimes added to provide additional carbon sources for lactic acid bacteria. In summer, ground barley bap is added to the seasoning to facilitate fermentation. During Winter kimchi making, *actjeot* (fermented fish sauce) or other *jeotgal* are added, which not only provide additional carbon sources for lactic acid bacteria but also enhance the overall flavor of kimchi. However, excessive carbohydrate addition should be avoided as it can lead to the rapid growth of spoilage bacteria, compromising the fermentation process. Thus, a delicate balance must be maintained to ensure optimal fermentation conditions without promoting spoilage.

Kimchi preservation

Traditional Preservation Methods: In Spring, when various vegetables sprout and grow in the fields and mountains, and in Autumn, when vegetables are grown up, kimchi can be enjoyed for up to a week after being made. However, in Summer, when temperatures rise, kimchi will sour quickly, and it becomes too sour after 3–4 days. In Winter, kimchi freezes easily, so lactic acid fermentation does not occur and the texture becomes soft and brittle, it becomes kimchi that cannot be eaten. Ancestors in Korea devised various methods to preserve kimchi throughout the seasons to overcome the deterioration process. They looking for cooler places to store kimchi to prevent spoilage. Traditionally, people dug underground storage spaces like tunnels to keep kimchi cool at temperatures between 5 and 10 °C. In areas without underground storage, small earthenware jars were hung inside wells or springs (3–5 m deep) using ropes (Fig. 3a), allowing kimchi to be stored and kept tasty for 5–6 days even

Fig. 3 Traditional kimchi storage methods. **a** Well-hanging storage system: Earthenware jars containing kimchi were suspended inside wells using ropes during spring and summer, maintaining palatability for 5–6 days even in warm weather. **b** Underground storage system (kimjang-dok): Winter kimchi storage involved burying sealed earthenware containers underground, insulated with straw. This method maintained optimal fermentation temperatures between − 2 and 5 °C throughout winter, preventing freezing while allowing continued fermentation until early spring. Well image sourced from Naver images; kimjang-dok image courtesy of World Institute of Kimchi (Gwangju, Korea)

during the Summer. Nonetheless, our ancestors could make kimchi only once or twice a week using the various vegetables available from Spring to Autumn.

However, during Winter, when the main vegetables for kimchi, such as cabbage and radish, were not available, vegetable availability posed a significant challenge. Not only was it impossible to obtain ingredients to make kimchi every week, but kimchi made in Winter would freeze due to the cold weather, rendering it inedible. To prevent this, before the onset of Winter, people would sow cabbage seeds and harvest them as soon as they were mature, typically before the first frost, to make enough kimchi to last through Winter. This process, known as kimjang [9], was a significant undertaking, with each household in the village making kimchi collectively (In 2013, UNESCO recognized this kimjang culture as an Intangible Cultural Heritage of Humanity). This tradition likely became more prevalent during the settled agricultural era, long after the discovery of kimchi.

Kimjang kimchi, made during this time, needs to be stored at a constant temperature to prevent freezing. To achieve this, kimchi was packed into kimchi jars and buried underground (Fig. 3b), typically reaching temperatures between − 2 to 5 °C, until the beginning of Spring. The fermented kimchi would be ready to eat by then. Radishes were also preserved by soaking them in salt water until fully matured, then sliced or chopped into pieces to be eaten throughout the Winter. This dish called "*sinkeonji*," or "*dongchimi*" (Fig. 1) in Korean, was highly sought after for its refreshing taste, particularly during the Winter. During the Choseon Dynasty, it was often recommended as a remedy for indigestion and was prescribed as a medicinal kuk called *'kimchi-kuk'* (kimchi soup). Additionally, in the pre-1980s era, when carbon monoxide poisoning from coal gas leaks in ondol rooms was a common occurrence, *singeonji*-kuk was administered as an emergency treatment to revive individuals who had lost consciousness from inhaling the gas.

Kimchi-dok (Kimchi Pots): Kimchi pots, traditionally made of earthenware, have been used for centuries, with historical records dating back to the Three Kingdoms period. These porous vessels, known as *ongki*, are ideal for fermenting and storing fermented foods like kimchi, kanjang (soy sauce), and doenjang (fermented bean paste) [32]. The porous walls in earthenware allow air circulation, regulating fermentation and imparting unique flavors to the stored food.

Microscopically, these pots feature countless tiny holes formed during firing, allowing air to pass through but retaining moisture. This porous structure supports lactic acid fermentation by providing a suitable oxygen supply and regulating microbial activity. Additionally, during fermentation, some carbon dioxide is released through these pores, contributing to the optimal fermentation environment inside the pot [33].

Buried underground, kimchi-dok maintains a constant temperature of around − 2 to 5 °C, preventing kimchi from freezing and ensuring its preservation until Spring. In Winter, kimchi from kimchi-dok is enjoyed without freezing, providing a source of nutrition and flavor during the cold season.

Kimchi Refrigerator: It revolutionizes kimchi preservation. As urbanization progressed, living environments shifted from individual houses to apartments, making it impractical to bury kimchi pots underground for preservation. However, kimchi remained an essential part of the Korean diet. During kimjang season, rural parents often prepared and delivered directly or partially fermented kimchi to their children in urban so that it could be stored in regular refrigerators.

Conventional refrigerators, however, posed challenges as they circulated cold air, causing temperature variations of up to 10 °C and dehydration. To address this, scientists (Jae-Keun Chun, Professor at Seoul National University) developed the kimchi refrigerator, a system specifically designed to preserve kimchi's fermentation properties and flavor over extended periods, serving as a modern alternative to traditional kimchi pots. The core technology of the kimchi refrigerator maintains a temperature ideal for kimchi fermentation (− 1 to 0 °C), initiates and controls lactic acid fermentation according to the type of kimchi, and prevents the formation of *golmaji* by regulating acidity levels [22]. These refrigerators feature a door mechanism that maintains temperature consistency even when opened, and they stabilize carbon dioxide levels generated during fermentation.

Over time, kimchi refrigerator technology has evolved to include optimal algorithms for generating and fermenting kimchi probiotics, ensuring the preservation of kimchi in its best state. Additionally, with the integration of artificial intelligence, kimchi refrigerators can adjust storage conditions based on different kimchi types like cabbage kimchi, green onion kimchi, cucumber kimchi, and young radish kimchi, as well as store various other ingredients. The invention of the kimchi refrigerator revolutionized Korean kimchi culture, allowing for year-round access to delicious kimchi. What used to require kimjang preparation every one or two weeks during Spring and Autumn can now be done once a month. *Sinkeonji* or *dongchimi* kimchi (Fig. 1), traditionally only available in Winter, can now be enjoyed throughout the year, and *mukeunji* (matured fermented kimchi over Winter) can be obtained anytime.

Kimchi *chigae* (stew), has evolved as a dish best enjoyed when kimchi is at its peak ripeness, just before it begins to sour. Therefore, it is much tastier when made with

ripened kimchi rather than fresh kimchi. Traditionally, during the melting of snow in Spring, kimchi *chigae* was enjoyed at its finest. However, thanks to kimchi refrigerators today, we can enjoy delicious kimchi *chigae* throughout the year. Additionally, *kamjatang* (simply meaning potato-tang), a spicy pork bone *tang* (stew), traditionally made with aged kimchi (*mukeun-ji*), was often enjoyed during early Summer when potatoes were plentiful. However, as aged kimchi is available year-round, *kamjatang* can now be enjoyed without the need for abundant potato harvests.

Why is it kimchi?

Why does kimchi taste so good?

Salt is the most delicious ingredient in the world, surpassing all others. Since our bodies contain 0.9% salt, they require a constant balance of salt to maintain health. This is the essential criterion for taste in our food, known as "*kan*" [7], it is reported the transient receptor potential vanilloid 1 (TRPV1) found only in mammals, is involved in this salt taste, *kan* [34]. While simply eating bap cannot satisfy this biological requirement, kimchi inherently tastes good because it is seasoned with salt and balanced in kan.

While vegetables themselves contain flavor compounds, garlic, green onions, and chili peppers contain phytochemicals such as allicin and capsaicin, which eliminate any unpleasant odors and add unique flavors on their own. TRPV1, a salt taste receptor, is also activated by capsaicin, stimulating the body through sensory perception when consumed in appropriate amounts via kimchi [35, 36].

During the fermentation process, kimchi undergoes lactic acid bacteria growth, producing lactic acid as a fermentation by-product. The sour taste in over-fermented kimchi results from excessive lactic acid production by fermentative lactic acid bacteria belonging to the *Lactobacillus* genus. Sourness is a taste humans inherently enjoy. Mannitol, produced as a fermentation by-product by bacteria such as *Weissella, Leuconostoc*, and *Lactobacillus*, contributes to the sweet taste of kimchi [37, 38]. Well-fermented kimchi produces a fizzy sensation similar to carbonated beverages due to the carbon dioxide produced by these lactic acid bacteria.

Kimchi fermentation not only softens the texture of the vegetables through the action of pectinase enzymes produced by the microbes, but it also produces various organic compounds by other enzymes [39]. These compounds collectively contribute to the overall flavor of kimchi, creating its unique taste. Particularly, as you chew, the distinct flavor of kimchi seeps out, resulting in a deeply satisfying taste. Unlike flavors derived from nutrition components, which can often become monotonous, the unique non-nutrition flavors found in kimchi, such as those produced during fermentation, are less likely to cause palate fatigue. In fact, many Korean people find themselves craving kimchi to the point where they feel they cannot enjoy a meal without it, attesting to its deeply ingrained appeal.

Why is kimchi safe?

Why does kimchi remain preserved as safe while namul or leafy greens spoil? The difference lies in fermentation versus decay. When people experience upset stomach after consuming aged foods, it indicates decay, but if they don't, it suggests fermentation. Bap or branched namul easily spoil because they are lifeless and lack inherent antimicrobial properties. However, kimchi contains living tissues and beneficial microorganisms within it. The fundamental difference between leafy greens and kimchi is the use of chili powder. Of course, since leafy greens are cooked, they generally have soft textures, while kimchi tends to have rougher textures [7]. Of course, the texture may become soft when soaked with salt, but it generally remains rough. Although it can be argued that vegetables with rough textures are inherently resistant to microbes, kimchi's safety stems from another reason.

Before fermenting kimchi, vegetables, especially cabbage, are salted, causing water to be drawn out from the cabbage cells in a hypertonic state. This not only deactivates spoilage bacteria, which are also in a hypertonic state but also allows lactic acid bacteria to thrive, leading to successful fermentation. Furthermore, capsaicin in chili powder controls other harmful bacteria, allowing only lactic acid bacteria to grow and maintain acidity by producing lactic acid [40]. The fact that capsaicin stimulates the growth of lactic acid bacteria is supported by research in microbiome studies, which show that capsaicin leads to the particularly abundant growth of lactic acid bacteria in the gut microbiota [41, 42]. The production of lactic acid during fermentation lowers the pH, maintaining a stable low acidity that prevents the growth of most spoilage bacteria, ensuring the longevity of kimchi.

However, in the past, kimchi fermentation would continue until it became overly sour and *golmaji* (fizziness) occurred due to yeast fermentation, making it inedible after a few days. With the modern development of refrigerators, especially kimchi refrigerators, fermentation can be controlled, allowing kimchi to be safely consumed for over a year. Moreover, "mukeun-ji," fermented for over a year, which pairs especially well with kimchi *chigae* and *kamjatang*, can also be made by fermenting cabbage kimchi (refer to the latter part for kimchi fermentation and ripening). The World Kimchi Research Institute confirmed the safety of the yeast responsible for *golmaji*

through toxicity experiments using cells and animals and genetic analysis, showing no specific toxicity reactions or genes related to toxicity [43]. Traditionally, when consuming kimchi, one removes the *golmaji* part, rinses it with water, then cooks it in dishes like kimchi *chigaes* and stir-fried kimchi (볶음김치).

Why is kimchi healthy?

In recent years, extensive research has been conducted on the health benefits of kimchi, including its raw materials, fermentation metabolites, and the health functionality of fermentative microorganisms such as probiotics, encompassing cell experiments, animal trials, and even human studies [44–46]. However, such research views kimchi, not as an important contributor to nutrition, but as a banchan consumed with bap, in other words, as a non-nutrient food. Therefore, evaluating kimchi nutritionally or in terms of its nutrient content may be meaningless.

Due to this perspective, during the Japanese colonial era, when nutrition was scarce, Koreans who didn't understand the essence of kimchi were viewed by the Japanese as ignorant people who consumed foods that were nutritionally worthless, spicy, and smelled of garlic or strange odors, which they believed ruined the stomach. As a result, Korean cuisine was misrepresented as salty and spicy, and it was openly taught that Koreans had a high incidence of stomach cancer. Even after liberation, this erroneous perspective continued to dominate the perception of our food in Korean higher education.

In essence, if one were to ask why kimchi is healthy, it could be summed up as follows: from the perspective of culinary development, kimchi is a healthy food because it allows bap to be eaten without using sugar and oil to enhance flavor. As everyone knows, in nourishment eras foods flavored with sugar and fried in oil at high temperatures (300–400 °C) led to obesity and many metabolic diseases. In modern times, when nutrition is often excessive, non-nutritional foods, particularly dietary fiber-rich foods, are highly regarded for their health benefits.

From a compositional standpoint, the primary component of kimchi, represented by cellulose, is dietary fiber, which is beneficial for preventing obesity and constipation [47]. The vegetables used in kimchi are rich in antioxidants. Peppers contain capsaicin, garlic contains allicin, and ginger contains gingerol, all of which are powerful antioxidants, anti-inflammatory agents, and anticancer substances. Additionally, kimchi contains substantial amounts of other antioxidants such as polyphenols, flavonoids, chlorophyll, and vitamin C. These phytochemicals play a crucial role in preventing metabolic diseases in our bodies [48].

Moreover, numerous studies have reported that metabolites produced from these substances during fermentation, as well as probiotics and postbiotics derived from the microbiome centered around lactic acid bacteria, have beneficial effects on our bodies [49, 50]. All the metabolites of kimchi, produced through the fermentation process of fiber-rich vegetables to lactic acid bacteria, can be considered health food components.

The lactic acid bacteria involved in kimchi fermentation act as probiotics. Examining the changes in the number of lactic acid bacteria according to the fermentation stage of kimchi reveals that they proliferate to over one billion per gram of kimchi [51]. Naturally fermented foods like kimchi contain a significant amount of lactic acid bacteria, comparable to artificially fermented yogurt. Considering the various benefits such as digestion enhancement, immune system regulation, improvement of atopic conditions and allergies, as well as anticancer and obesity prevention effects attributed to kimchi lactic acid bacteria, kimchi is expected to play a significant role as both a probiotic and postbiotic [52–54].

"Why don't Koreans get tired of eating kimchi with everymeal?"

Koreans often say, "We can't eat a meal without kimchi." Foreigners find this difficult to understand. Why don't Koreans get tired of eating kimchi with every meal? Most Koreans answer that it's because "it's ingrained in us." This scientifically inexplicable reason seems to be due to the unique flavor characteristics of kimchi. The flavor of kimchi is characterized by its sourness and refreshing taste, which come from lactic acid produced by lactic acid bacteria fermentation and carbonic gas. For Koreans, having the right level of saltiness (kan) is very important. Fermented kimchi has an appropriate level of kan, produces umami-giving fermented substances, and has a sour and refreshing taste. Because it doesn't have any stale or greasy flavors, this could be why Koreans don't get tired of eating it no matter how much they consume.

Recent advances in life sciences may help us understand scientifically the old Korean saying, "Kimchi becomes ingrained in you, so you never get tired of eating it." The development of epigenomics suggests that our eating habits can be influenced by epigenetics and even passed down to future generations [55]. In other words, it seems that Koreans have an epigenetic imprint that prevents them from getting tired of eating kimchi, no matter how much they consume. It appears that some protein modification involved in genetics has created a habit in Koreans of seeking out kimchi without getting tired of it. Studying Korean eating habits and the health effects of kimchi from this epigenetic perspective could be an excellent research topic.

Conclusions

Kimchi stands as a unique culinary and cultural phenomenon, distinguishing itself as the world's sole lactic acid-fermented vegetable dish originating from Korea. Its discovery and development can be viewed as a serendipitous gift, born from the intersection of necessity, innovation, and natural processes. The preparation of kimchi showcases a deep understanding of vegetable properties and fermentation techniques, with soft vegetables directly seasoned using a core mixture of ingredients including red pepper powder, garlic, ginger, and fish sauce, while coarser vegetables undergo a pre-treatment process of salting to soften their structure before fermentation. This meticulous process results in a product with unparalleled characteristics in taste, appearance, and functionality, setting kimchi apart from other fermented vegetable dishes globally.

The unique sensory profile of kimchi, often referred to as 'kimchi essence', arises from a complex interplay of flavors and aromas. The spiciness of red pepper, the pungency of garlic and ginger, the umami depth of fish sauce, and the natural flavors of main ingredients such as cabbage, radish, and cucumber create a distinctive combination. This sensory experience distinguishes kimchi from pickled vegetables found in other culinary traditions, such as China's pao chai, Japan's tsukemono, Germany's sauerkraut, and Mediterranean pickles. The appeal of kimchi extends beyond its taste profile to encompass significant health benefits. The lactic acid produced during fermentation contributes to kimchi's delicious flavor while also acting as a natural preservative. The lactobacilli involved in the fermentation process serve as probiotics, offering potential health benefits to the consumer. Notably, even when kimchi is cooked, as in chigae (stew), the cellular components of the lactic acid bacteria continue to provide health benefits as postbiotics. Therefore, kimchi represents a remarkable convergence of culinary art, cultural tradition, and nutritional science. Its unique preparation methods, distinctive flavor profile, and health-promoting properties make it not just a food, but a testament to the ingenuity and wisdom of Korean culinary heritage. As global interest in fermented foods and probiotics continues to grow, kimchi stands poised to play an increasingly significant role in international cuisine and nutrition, bridging traditional practices with modern health consciousness.

Acknowledgements
This research was done with the support of Korea Food Research Institute in part.

Author contributions
DYK conceptualized and designed manuscript structure and collected the data or wisdom in terms of history and science, CHL and SHK contributed kimchi fermentation and capsaicin data, KRC surveyed old literature books and documents, SP contributed to conceptualization and writing and JWD contributed to writing & editing.

Funding
Not applicable.

Availability of data and materials
This data and materials related to this study are available upon request.

Declarations

Ethics approval and consent participate
Not applicable.

Consent for publication
All authors have read and approved the consent of the manuscript for publication.

Competing interests
The authors declare that they have no competing interests.

Received: 22 October 2024 Accepted: 4 February 2025
Published online: 26 February 2025

References

1. Park KY, Cheigh HS. Kimchi. In: Hui YH, Meunier-Goddik L, Josephsen J, Nip WI, Stanfield PS, editors. Handbook food and beverage fermentaion technology. Chapter 35, 41. Cambridge: CRC Press; 2004.
2. Kwon DY, Chung KR, Daily JW, Park S. Geohistorical Evolution of Kimchi as an Ethnic Food. J Ethn Food, 2024 In press.
3. Kwon DY. Diet in Korea. In: Meiselman HL, editor. Handbook of eating and drinking. Cham: Springer; 2020. p. 1435–65.
4. Kwon DY. The answer for a healthy life is a Korean traditional diet. In: Kalidas S, Shin DH, editors. Korean food system. New York: CRC Press; 2022. p. 65–106.
5. Kwon DY. Humanities of Korean foods (in Korean). Seoul: Health Letter; 2019.
6. Kim SH, Ko J, Kwon DY. Jang, Korean fermented soybean product, the result of endeavors of ancients for the best taste of Korean diet. J Ethn Foods. 2023;10:33. https://doi.org/10.1186/s42779-023-00183-6.
7. Kwon DY, Kim SH, Chung KR, Daily JW, Park S. Science and philosophy of Korea traditional foods (K-food). J Ethn Foods. 2023;10:26. https://doi.org/10.1186/s42779-023-00194-3.
8. Jung SJ, Chae SW, Shin DH. Fermented foods of Korea and their functionalities. Fermentation. 2022;8:645. https://doi.org/10.3390/fermentation8110645.
9. Surya R, Lee AG. Exploring the philosophical values of kimchi and kimjang culture. J Ethnic Foods. 2022;9:20. https://doi.org/10.1186/s42779-022-00136-5.
10. Patra JK, Das G, Paramithiotis S, Shin HS. Kimchi and other widely consumed traditional fermented foods of Korea: a review. Front Microbiol. 2016. https://doi.org/10.3389/fmicb.2016.01493.
11. Oh SH, Park KW, Daily JW, Lee YE. Preserving the legacy of healthy Korean food. J Med Food. 2014;17:1–5. https://doi.org/10.1089/jmf.2014.1701.ed.
12. Kim J, Bang J, Beuchat LR, Kim H, Ryu JH. Controlled fermentation of kimchi using naturally occurring antimicrobial agents. Food Microbiol. 2012;32:20–31. https://doi.org/10.1016/j.fm.2012.05.007.
13. Jung JY, Lee SH, Jeon CO. Kimchi microflora: history, current status, and perspectives for industrial kimchi production. Appl Microbiol Biotechnol. 2014;98:2385–93. https://doi.org/10.1007/s00253-014-5513-1.
14. Codex Alimentarius Commission (Codex), Codex Standard for Kimchi. Codex Standard 223. Food and Agriculture Organization of the United Nations, 2001, Rome, Italy
15. Lee JS, Chun CO, Jung MC, Kim WS, et al. Classification of isolates originating from kimchi using carbon-source utilization patterns. J Microbiol Biotechnol. 1997;7:68–74.

16. Choi HJ, Lee J, Jang JY. Lactic acid bacteria in kimchi. In: Park KY, Kwon DY, Lee KW, Park S, editors. Korean functional foods, composition, processing and health benefits. New York: CRC Press; 2018. p. 79–100.
17. Park JM, Shin JH, Lee DW, Song JC, Suh HJ, Chang UJ, Kim JM. Identification of the lactic acid bacteria in Kimchi according to initial and over-ripened fermentation using PCR and 16S rRNA gene sequence analysis. Food Sci Biotechnol. 2010;19:541–6. https://doi.org/10.1007/s10068-010-0075-1.
18. Kim B, Seo WT, Kim MG, Yun HD, Cho KM. Metagenomic lactic acid bacterial diversity during *Mul*-kimchi fermentation based on 16S rRNA sequence. J Korean Soc Appl Biol Chem. 2012;55:787–92. https://doi.org/10.1007/s13765-012-2185-3.
19. Park B, Yang JS, Moon EW, Seo HY, Ha JH. Influence of capsaicinoids content on the microbial community during kimchi fermentation. J Microbiol Biotechnol. 2019;29:1580–90. https://doi.org/10.4014/jmb.1907.07023.
20. Ku YJ, Choi SY. Science and technology of kimchi. Seoul: Korea Food Research Institute; 1990. p. 125–34.
21. Cheigh HS, Park KY, Lee CY. Biochemical, microbiological, and nutritional aspects of kimchi. Crit Rev Food Sci Nutr. 1994;34:175–203. https://doi.org/10.1080/10408399409527656.
22. Kim MJ, Lee HW, Kim JY, Kang SE, et al. Impact of fermentation conditions on the diversity of white colony-forming yeast and analysis of metabolite changes by white colony-forming yeast in kimchi. Food Res Int. 2020;136:109315. https://doi.org/10.1016/j.foodres.2020.109315.
23. Moon SH, Chang M, Kim HY, Chang HC. *Pichia kudriavzevii* is the major yeast involved in film-formation, off-odor production, and texture-softening in over-ripened Kimchi. Food Sci Biotechnol. 2014;23:489–97. https://doi.org/10.1007/s10068-014-0067-7.
24. Cha J, Kim YB, Park S-E, Lee SH, et al. Does kimchi deserve the status of a probiotic food? Crit Rev Food Sci Nutr. 2023. https://doi.org/10.1080/10408398.2023.2170319.
25. Swamy KRM. Origin, distribution, taxonomy, botanical description, genetic diversity, and breeding of Capsicum (*Capsicum annuum* L.). Int J Dev Res. 2023;13:61956–77.
26. Berger Z, Salinas AB, Pongrácz GS. A biographical sketch of Albert Szent-Györgyi. Rev Med Chile. 2015;143:1065–9.
27. Lim SB, Shin SY, Moon JS, Otgonbayar G-E, Joo W, Lee SJ, Jeon CO, Han NS. Garlic is a source of major lactic acid bacteria for early-stage fermentation of cabbage-kimchi. Food Sci Biotechnol. 2015;24:1437–41. https://doi.org/10.1007/s10068-015-0184-y.
28. Lee SH, Jung JY, Jeon CO. Source tracking and succession of kimchi lactic acid bacteria during fermentation. J Food Sci. 2015;80:M1871–7. https://doi.org/10.1111/1750-3841.12948.
29. Han ES. History of kimchi and industrial development. In: Shin DH, editor. Korean fermentation foods. Seoul: Sikanyon; 2021. p. 193–267.
30. Aboyeji CM, Adekiya AO, Dunsin O, Agbaje GO, Olugbemi O, Okoh HO, Olofintoye TAJ. Growth, yield and vitamin C content of radish (*Raphanus sativus* L.) as affected by green biomass of *Parkia biglobosa* and *Tithonia diversifolia*. Agrofor Syst. 2019;93:803–12.
31. Jung MY, Kim TW, Lee C, Kim JY, Song HS, Kim YB, Ahn SW, Kim JS, Roh SW, Lee SH. Role of jeotgal, a Korean traditional fermented fish sauce, in microbial dynamics and metabolite profiles during kimchi fermentation. Food Chem. 2018;265:135–43. https://doi.org/10.1016/j.foodchem.2018.05.093.
32. McGovern P, Jalabadze M, Batiuk S, Lordkipanidze D. Early Neolithic wine of Georgia in the South Caucasus. PNAS. 2017;114:E10309–18. https://doi.org/10.1073/pnas.1714728114.
33. Kim SH, Hu DL. Onggi's permeability to carbon dioxide accelerates kimchi fermentation. 2023. J R Soc Interface. https://doi.org/10.6084/m9.figshare.c6486200.
34. Lyall V, Heck GL, Vinnikova AK, Ghosh S, Phan THT, Alam RI, Russell OF, Malik SA, Bigbee JW, DeSimone JA. The mammalian amiloride-insensitive non-specific salt taste receptor is a vanilloid receptor-1 variant. J Physiol. 2004;558:147–59. https://doi.org/10.1113/jphysiol.2004.065656.
35. Tewksbury JJ, Nabhan GP. Directed deterrence by capsaicin in chilies. Nature. 2001;412:403–4.
36. Yang F, Xiao X, Lee BH, Vu S, Yang W, Yarov-Yarovoy V, Zheng J. The conformational wave in capsaicin activation of transient receptor potential vanilloid 1 ion channel. Nat Commun. 2018;9:2879. https://doi.org/10.1038/s41467-018-05339-6.
37. Ha JH, Hawer WS, Kim YJ, Nam YJ. Changes of free sugars in kimchi during fermentation. Korean J Food Sci Technol. 1989;21:633–8.
38. Lee JJ, Choi YJ, Lee MJ, Park SJ, et al. Effects of combining two lactic acid bacteria as a starter culture on model kimchi fermentation. Food Res Int. 2020;136: 109591. https://doi.org/10.1016/j.foodres.2020.109591.
39. Choi YJ, Yong Y, Lee MJ, Park SJ, et al. Changes in volatile and non-volatile compounds of model kimchi through fermentation by lactic acid bacteria. LWT. 2019;105:118–26. https://doi.org/10.1016/j.lwt.2019.02.001.
40. Agarwal P, Das C, Dias O, Shanbhag T. Antimicrobial property of capsaicin. Int Res J Biol Sci. 2017;6:7–11.
41. Rosca AE, Iesanu MI, Zahiu CDM, et al. Capsaicin and gut microbiota in health and disease. Molecules. 2020;25:5681. https://doi.org/10.3390/molecules25235681.
42. Xiang Q, Tang X, Cui S, Zhang Q, et al. Capsaicin, the spicy ingredient of chili peppers: effects on gastrointestinal tract and composition of gut microbiota at various dosages. Foods. 2022;11:686. https://doi.org/10.3390/foods11050686.
43. Jeong CH, Kim JY, Oh YJ, Ko HI, et al. Safety assessment of white colony-forming yeasts in kimchi. Food Microbiol. 2022. https://doi.org/10.1016/j.fm.2022.104057.
44. Park KY, Ju J. Kimchi, and health benefits. In: Park KY, Kwon DY, Lee KW, Park S, editors. Korean functional foods, composition, processing, and health benefits. New York: CRC Press; 2018. p. 43–77.
45. Park KY, Hong GH, Lee SY, Lee Y. Kimchi and its antiobesity and anticancer functions. J Ethn Food, 2024 (in this issue)
46. Lee W, Kwon M-S, Yun Y-R, et al. Effects of kimchi consumption on body fat and intestinal microbiota in overweight participants: a randomized, double-blind, placebo-controlled, single-center clinical trial. J Funct Foods. 2024;121: 106401. https://doi.org/10.1016/j.jff.2024.106401.
47. Nagano T, Yano H. Dietary cellulose nanofiber modulates obesity and gut microbiota in high-fat-fed mice. Bioactive Carbohydr Diet Fibre. 2020;22:100214. https://doi.org/10.1016/j.bcdf.2020.100214.
48. Na HK, Surh YJ. Yangnyeom (spices) and health effects. In: Park KY, Kwon DY, Lee KW, Park S, editors. Korean functional foods, composition, processing, and health benefits. New York: CRC Press; 2018. p. 257–90.
49. Jeong SH, Lee SH, Jung JY, Choi EJ, Jeon CO. Microbial succession and metabolite changes during long-term storage of kimchi. J Food Sci. 2013;78:M763-769. https://doi.org/10.1111/1750-3841.12095.
50. Lee SJ, Jeon HS, Yoo JY, Kim JH. Some important metabolites produced by lactic acid bacteria originated from kimchi. Foods. 2021;10:2148. https://doi.org/10.3390/foods10092148.
51. Kim HY, Bong YJ, Jeong JK, Park KY. Heterofermentative lactic acid bacteria dominate in Korean commercial kimchi. Food Sci Biotechnol. 2016;25:541–5. https://doi.org/10.1007/s10068-016-0075-x.
52. Kim B, Mun EG, Kim D, Kim Y, Park Y, Lee HJ, Cha YS. A survey of research papers on the health benefits of kimchi and kimchi lactic acid bacteria. J Nutr Health. 2018;51:1–13. https://doi.org/10.4163/jnh.2018.51.1.1.
53. Vera-Santander VE, Hernández-Figueroa RH, Jiménez-Munguía MT, Mani-López E, López-Malo A. Benefits of consuming foods with bacterial probiotics, postbiotics, and their metabolites: a review. Molecules. 2023;28:1230. https://doi.org/10.3390/molecules28031230.
54. Wastyk HC, Fragiadakis GK, Perelma D, et al. Gut-microbiota-targeted diets modulate human immune status. Cell. 2021;184:4137–53. https://doi.org/10.1016/j.cell.2021.06.019.
55. Gabbianelli R, Bordoni L, Morano S, Calleja-Agius J, Lalor JG. Nutri-epigenetics and gut microbiota: how birth care, bonding, and breastfeeding can influence and be Influenced? Int J Mol Sci. 2020;21:5032. https://doi.org/10.3390/ijms21145032.

Publisher's Note