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Korean traditional fermented fish products: *jeotgal*Ok Kyung Koo^{a,*}, Soo Jung Lee^b, Kyung Rhan Chung^c, Dai Ja Jang^d, Hye Jung Yang^d, Dae Young Kwon^{d,*}^a Department of Food and Nutrition, Gyeongsang National University, Jinju, South Korea^b Institute of Agriculture and Life Science, Gyeongsang National University, Jinju, South Korea^c The Academy of Korean Studies, Songnam, South Korea^d Food Safety Research Group, Korea Food Research Institute, Songnam, South Korea

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ABSTRACT

Jeotgal (醃) is a traditional Korean fermented food with thousands years of history with *kimchi* and other *jang* (fermented soybean products, 醬). The history was proved by research from historical literature and antique architecture. *Jeotgal* was developed along with *jang* (豆醬), fish *jang* (魚醬), meat *jang* (肉醬) as a part of *jang* (醬) up to the Chosun Dynasty and it was always offered during the ancestral rites or ceremonies. According to antique documents written by women, *jeotgal* had been used as seasonings or condiments that were popular especially for women rather than as food served for ancestral rites. In Southeast Asia and other countries, *jeotgal* uses varieties of fish and seafoods to provide rich and varied flavors, and thanks to the next generation sequencing technology, we can identify microorganisms that are involved in the fermentation process. Major microorganisms in *jeotgal* are *Bacillus*, *Brevibacterium*, *Micrococcus*, *Pediococcus*, *Pseudomonas*, *Lactobacillus*, *Leuconostoc*, and *Halobacterium*. Recently, much research on various health function of *jeotgal* has been conducted, reflecting increasing interest in the safety and the functionality of *jeotgal*. Many reports on functionalities of *jeotgal* such as supplying essential amino acids, and having antioxidant and antitumorigenic have been published recently. Because of the diverse flavor, types, and their function, *jeotgal* is expected to continue to develop as an important seasoning in the world sauce market.

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1. Introduction

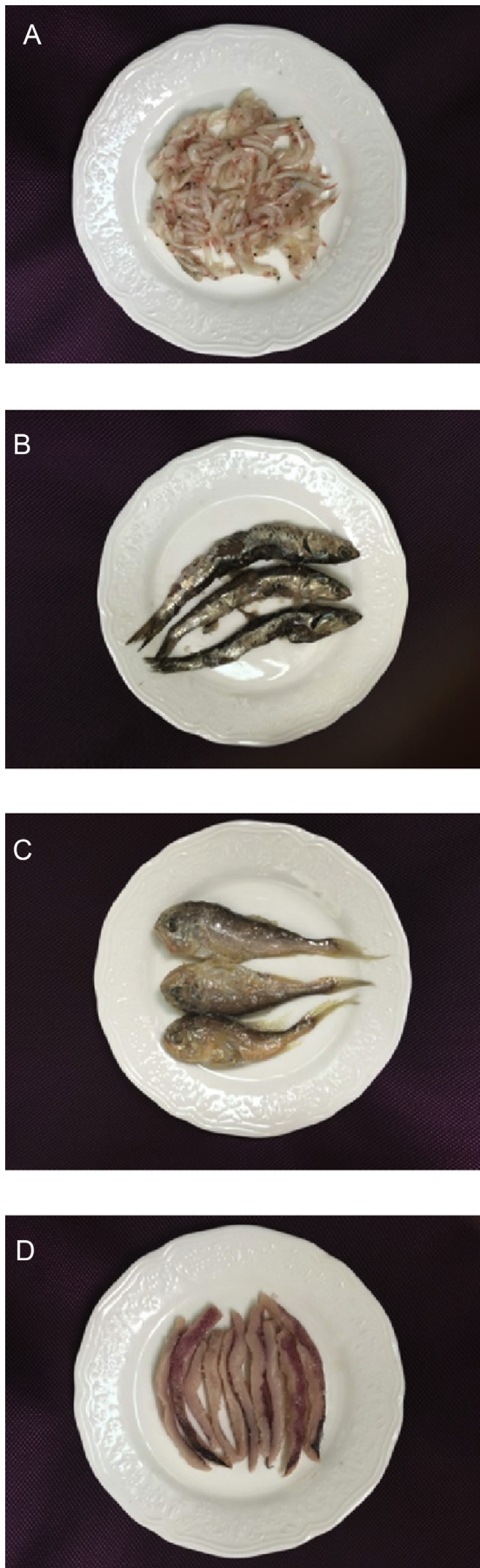
Much of the food technology development in food products has been motivated by the desire to preserve food in good condition for future consumption [1]. Each country has developed unique ways of preserving food, especially meat and fish. The most prevalent method of preservation is through reducing water activity by adding salt or drying, which protects against microbial spoilage by inhibiting the growth of harmful microorganisms. Fish, for example, was usually salted down immediately in order to prevent spoilage. It is presumed that food would ferment during this preservation process by beneficial microorganisms. As

fermentation does not lead to any health issues, people would have continued to consume fermented foods even if they had never come to understand how fermentation changes food. In the Orient, fermented foods have been produced using beans, fish, and meat, and the general term for these products is *jang* (醬) [2,3]. *Jang* made from beans is referred to as *dujang* (豆醬, soy *jang*), from fish as *eojang* (魚醬, fish *jang*), and from meat as *yukjang* (肉醬, meat *jang*) [3]. *Dujang*, a representative type of *jang* in Korea, has been discussed previously in this journal [4]. At present times, the variation in *yukjang* (肉醬) such as this was limited, although *jang-jorim*, beef salted in soy sauce, was widely enjoyed, [1,5]. The most preferred type of salted and fermented food in Korea is *eojang* (魚醬), which is made with salted fish and is referred to as *jeotgal*. Fermented fish products have developed into other unique forms across East Asia, Southeast Asia, and Europe.

Fermented fish products have been consumed as the fish itself, fish sauce, fish paste, and other types of food throughout the world. Some of the examples of fish sauces are *jeotkal* in Korea [6], *shott-suru* from Japan [7], *nuoc-man* from Vietnam [3], various fermented

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fish products in India [8], *hakarl* in northern Europe [9], and Worcestershire sauce in England, which is mostly manufactured from anchovies; these are liquid type of sauces [10]. Fish pastes, which are made with minced or blended fish or shellfish include *padaek* from Laos, *prahok* from Cambodia, and shrimp paste from China [10]. These types of food are consumed as proteinaceous staples or condiments in Southeast Asia while northern Europeans consume them as condiments [8]. Korean *jeotgal* refers to both liquid and paste types of fermented fish foods.

Jeotgal is a traditional fermented fish food in Korea that is produced from the whole meat (Fig. 1) and/or internal organs of fish and shellfish (Fig. 2), salted and fermented for inhibition of spoilage, for autolysis, and for decomposing the main ingredients by microbial activities [11,12]. Unlike salted food to minimize the decomposition of the meat by harmful microorganisms, *jeotgal* produces a unique flavor during the protein decomposition of raw materials by beneficial organisms. As *jeotgal* has thousands of years of history, it has its own unique and many different characters [2,13]. Not only does proteolysis proceed during fermentation, but also carbohydrates, lipids, and organic acids are broken down to enhance the flavor, so that *jeotgal* is one of the important sub-ingredients or seasonings in *kimchi* and other Korean foods [14]. Traditionally, fish products have been a great source of protein in the Korean diet, but have varied in how they are consumed. For example, *hongeo* (fermented skate) [15] (Fig. 3A) is prepared with strong fermentation while *gulbi* (salted yellow corvina) [15] (Fig. 3B) is preserved by salting and drying without additional fermentation. In preparations such as *myeongtae* (dried pollock) and *hwangtae* (dried, aged pollock), another fish product for protein source, fish are frozen first and then dried to prevent spoilage without adding salt [16].

Jeotgal has great nutritional value with additional function to our health including appetite, digestion, and beneficial microorganisms. Many reports have focused on the production of Korean fermented fish products [11,17]. However, there are a few papers on the historical/cultural background and value added and beneficial effects of Korean fermented fishery products. Moreover, *jeotgal* has been underestimated as a food with high sodium content. Therefore, we have evaluated this high-added value food, *jeotgal*, from the history to the scientific data analysis in this article. We will discuss the origin and history of *jeotgal*, characterize and classify different types of *jeotgal* and provide the microbial community and health functional information of *jeotgal*.

2. History of *jeotgal*

Hae (醃; Fig. 4) is the Chinese character that generally represents *jeotgal*. Written references to this character are found in historical Chinese literature, including the *Sigyung* (詩經; BCE 551–477) [19] and *Lyeki* (禮記) [20], a book that details the courtesy observed during the Zhou (周) dynasty (BCE 1046–256), although written later, in the Han (漢) dynasty (BCE 202–CE 220). Although the references mainly discuss *yukjang* (肉醬), salted or fermented meat products, the use of term *ranhae* (卵鯉) suggests that *eojang* (魚醬) might have existed as a type of *jeotgal*. *Ja* (鮓), the Chinese character referring to *jeotgal* made with fish, first appeared in the *Cheminyosul* (齊民要術; CE 532), written by Ka (賈思勰) of the Shandong peninsula (山東半島) in China [2]. At that time, the Yodong peninsula (遼東半島) was under Kokuryu (高句麗, BCE 37–CE 668) rule, and there were many interactions among Kokuryu, Baekje (百濟, BCE

Fig. 1. *Jeotgal* prepared with whole fish by adding salt. (A) *Saeu-jeot* (small shrimp *jeot*), (B) *myeolchi-jeot* (anchovy *jeot*), (C) *whangseokeojeot* (yellow corvina *jeot*), and (D) *ojingeojeot* (squid *jeot*). (See Table 1.)

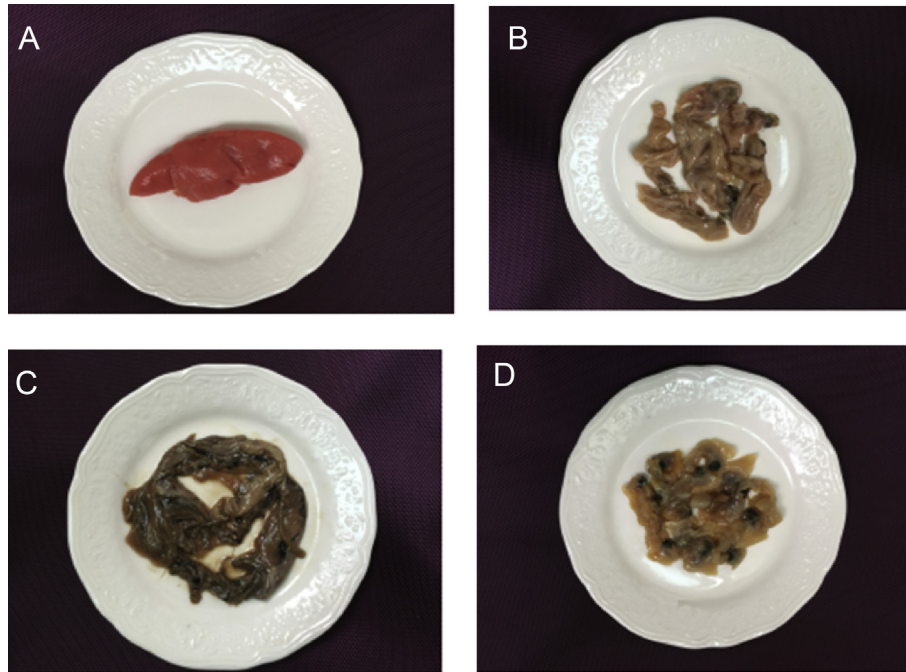


Fig. 2. Jeotgal fermented with internal parts of fish products. (A) Myeongranjeot (jeot with roe from pollock), (B) changnanjeot (jeot from intestine of pollock), (C) kalchisokjeot (jeot from intestine of cutlass), and (D) chogejeot (jeot with clam).

18–CE 660), and Sandong peninsula. Therefore, it is presumed that customs discussed in the *Cheminyosul* were related to the customs of Kokuryu or Baekje rather than those of Southern China. Moreover, the *Cheminyosul* introduced preserved fish food products that were salted or wrapped in lotus leaves and resembled fish jeotgal in Korea [21].

In Korea, in addition to *hae* (醃), *hye* (醃), which is another Chinese character for jeotgal, is mentioned in other literary works. For example, this character can be found in the *Samkuksaki* (三國史記) [22] and on a wooden tablet excavated in Anapji (雁鴨池) [23], Kyungju in Korea, which described the dietary aspect of royal life in the Shilla (新羅) dynasty [23,24]. The *Samkuksaki* mentioned that jeotgal (醃) was served at the royal wedding for King Sinmun (神文王, CE 681–692) [22]. It is presumed that the jeotgal (醃) introduced on the wooden tablet is the same *eojang* (魚鮓) as found in the *Cheminyosul* in Sandong peninsula. The jeotgal (醃)¹ from the wooden tablet, along with the one that appeared in the *Samkuksaki*, suggests that the history of jeotgal can be traced back hundreds of years. It also suggests that the unique categories of fermented food products established after the Shilla dynasty are different from the traditional Chinese references [2]. Fermented food products made with fish were referred to as *hae* (醃, 醃; jeotgal), meat as *damhae* (醃醃; fermented pork), *tohae* (兔醃; fermented rabbit), or *nokhae* (鹿醃, fermented venison), and bean as *jang* (醬) [25]. According to the *The Annals of King Sejong and Geography (Sejongsilrokjiriji, 世宗實錄地理志)* [26] and *The Annals of the Chosun Dynasty (Chosunwangjosilrok, 朝鮮王祖實錄)* [27], jeotgal was made with not only fish but also pork, rabbit, or venison, and was also consumed with

¹ There has been an issue with 醃, the Chinese character for jeotgal written on the wooden tablet. Some have claimed that the character on the wooden tablet is not the same word the 醃 or 醃 (jeotgal) that was used in the *Hunmongjahoe* (訓蒙字會) [18] (Fig. 4). However, the character on the wooden tablet is the same word as 醃, but with a different way of writing 酉 or 皿. It is regrettable that same character on the wooden tablet cannot be expressed in Microsoft Word (Microsoft Corporation, Redmond, WA, USA).

kimchi prior to the Chosun period. In those periods, the meaning of jeotgal was different from that now. Currently jeotgal generally refers to fermented food products made with fish.

A great number of references to jeotgal can be found within literature from the Chosun dynasty. The *Koryosa* (History of Koryo Dynasty, 高麗史) [28] and the *Koryosajeolyo* (Brief History of Koryo Dynasty, 高麗史節要) [29], history books written during the Chosun dynasty and covering the Koryo dynasty, used the expression “to make a person into jeotgal” to describe cruel execution methods used on criminals (Fig. 5). A similar expression is also found in the *Mokeunjip* (牧隱集) [30], written in 1404 by Lee (李穡)². This expression, which drew a parallel between tearing *kimchi* into pieces and hacking people into pieces, was described in a previous paper [31]. These references suggest that *poki-kimchi* (*kimchi* made from whole cabbage) and jeotgal have both existed for a long period of time. From this position, the claim that the history of *kimchi* has spanned less than 100 years, based on Joo's [32] erroneous argument that *gochu* pepper came from Japan during the Imjin War (CE 1592), cannot be substantiated.

Various sources, including the *Chosunwangjosilrok*, a book written during the Chosun dynasty, introduce jeotgal that was made with a variety of seafood products, such as *saeujeot* (紫蝦醃, shrimp jeot), *taegu-aljeot* (卵醃, cod roe jeot), *dwaejjkogijeot* (醃醃, pork jeot), *dalpaengijeot* (蝸醃, snail jeot), *kajamisikhae* (食醃, flatfish shikhae), *jogijeot* (黃魚醃, yellow corvina jeot), and *songeo-aljeot* (松魚醃, trout roe jeot) [33,34]. Records of having upset stomachs after eating jeotgal are also commonly found in the literature. Books that contain recipes for jeotgal were published beginning in the 17th century, both by male and female authors. The *Sallimkyongje* (山林經濟), a book written by a male author, Hong [35] (洪萬選), introduced a recipe for *saeujeot* (紫蝦醃, shrimp jeot) and recommended adding it to *kuk* made with meat, fish, or tofu. In the *Jungbo*

² “Who would resolve the chagrin of Hanpaeng (韓彭) after he was teared out like *kimchi* and jeotgal?” / 韓彭菹醃兔誰雪 / 韓彭菹醃兔誰雪

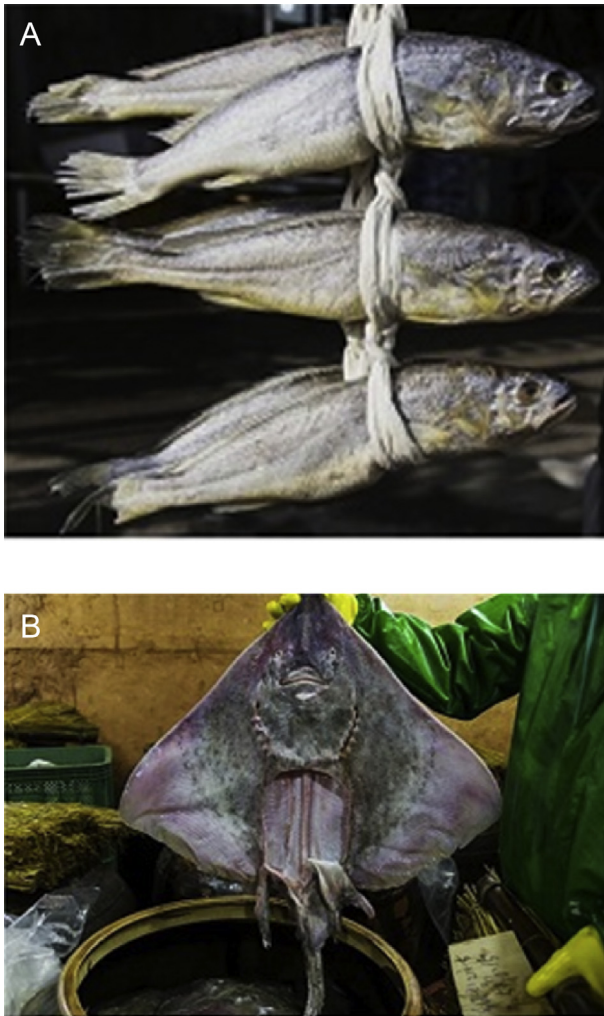


Fig. 3. (A) Fermented *hongeo* (*hongeo* from Heuksando: 黑山島, Black Mountain Island) with rice straw for a couple of days after fishing. (B) *Gulbi* (croaker from Yeongkwang: Yeongkwang *gulbi*), which is prepared by drying after saline treatment [15].

Sallimkyongje (增補山林經濟) [36], Yu (柳重臨) discussed recipes that used salt, rice wine lees, alcohol, soy sauce, pepper, green onions, glutinous rice, and malt in various *jeotgal*, such as *cheongeojot* (herring *jeot*), *saeujeot*, *daehapjeot* (clam *jeot*), *saengkuljeot* (raw oyster *jeot*), and *gejeot* (crab *jeot*), or *kanjang-gejang* (crab marinated in soy sauce) [12,36]. On special occasions, including royal court ceremonies, ancestral rites, and parties, fermented meat and fish products such as *tokkijeot* (兔醃, rabbit *jeot*), *saseumjeot* (鹿醃, venison *jeot*), *dwaenjeot* (醃醃, pork *jeot*), and *mulgokijeot* (魚醃, fish *jeot*) were served [37,38]. These records demonstrate that a wide range of ingredients was used in making *jeotgal*, while only salt and fish products are the main ingredients today.

As opposed to the works of male writers, books written by female authors described recipes for *jeotgal* in Hangul. For example, Jang [39] (Andong-張) discussed recipes for *cheongeojot* (herring *jeot*), *gejeot*, *yeoneo-aljeot* (salmon roe *jeot*), and *chamsaejeot* (sparrow *jeot*) in her book *Food-dimibang* (*Eumsikdimibang*, 閩臺是議方) using Hangul (Fig. 6). She also gave detailed information on *gejeot*, which was later developed into *kanjang-gejang*. In the *Kyuhapchongso* (閩閩叢書), published by Lee [40] (Bingheogak 李) in 1809, recipes for *gejeot* were introduced. *Gejeot* was salted with not only sodium but also soy sauce, alcohol, and vinegar. It was also seasoned with green onions and Korea red peppers without seeds.

This recipe is similar to the current *kanjang-gejang* recipe, showing that *kanjang-gejang* has been enjoyed among Koreans for quite some time.

The *Siuijonseo* (是議全書) [41], another cookbook written by a female author in the late 1890s, exclusively explained the types of fermented fish products (魚醃) and their recipes. This was different from previous books that discussed fermented meat products (肉醃) as well. In the *Siuijonseo*, almost all types of fish *jeotgal* were mentioned, including *jeotgal* consumed today, such as *jokijeot*, *myeolchijeot* (anchovy *jeot*), *saeujeot*, *jogaejeot* (clam *jeot*), *ojingeojot* (squid *jeot*), *cheongeojot*, *guljeot* (oyster *jeot*), and *aljeot* (roe *jeot*). *Jeotgal* mentioned in cookbooks published in the 20th century showed great similarity to contemporary *jeotgal*. References to fermented meat products (肉醃), which were generally served during royal ancestral rituals and other rites, cannot be found in literature published after the 17th century, other than in the *Cheminyosul* [2]. Cookbooks written by female writers mainly discussed fermented fish products. While the *Eumsikdimibang* [39] briefly introduced *chamsae-jeot* (sparrow *jeot*), which was made with poultry, both the *Kyuhapchongseo* and the *Siuijonseo* were exclusively concerned with fermented products made with fish.

It is presumed that these female authors wrote the books based on their own experience of making *jeotgal*. Thus, in daily life, common people would have enjoyed fermented fish products more than other fermented meat products. The term *jeotgal* currently refers to fermented fish products only. Fermented fish products were served as the main source of foods for common people, while fermented meat products were used as a food served at royal ancestral ritual or others. Therefore, this paper will focus on the current view of *jeotgal*, which involves only fermented fish products, rather than the traditional definition of *jeot* (醃).

3. Modern classification of *jeotgal*

Seafood is highly perishable food due to the high moisture content and highly nutritive in protein and fat for the growth of spoilage microorganisms [42]. *Jeotgal* was a very brilliant process to maximize the use of seafood in ancient to avoid deterioration. Namely, *jeotgal* is processed by conversion of the deterioration, resulting in a unique flavor and a preserved food product [1,17]. *Jeotgal* has been an important condiment in *kimchi* and not only as condiment, but also as dipping sauce for broiled pig's feet (*jokbal*), blood/noodle sausage (*sundae*). *Jeotgal* has also been added as seasoning to substitute salt or soy sauce in Korean style stews, *chigae* [1], and *kuk* and *tang* [43]. *Saeujeot* (shrimp *jeot*) is the most commonly used salt substitutive seasoning [17]. More than 150 types of *jeotgal* have been reported and they can be classified by the main ingredients, processing method and processing region.

3.1. Classification by main ingredients

Whole fish: Any fresh fish, crustaceans, and mollusks can be used to make *jeotgal* and each *jeotgal* is named after the main fish ingredients. In most cases, whole fish, shellfish, or crustaceans are used to produce *jeotgal*. However, a specific part of fish such as gills, intestine, or roe can be used. Therefore, *jeotgal* is classified based on the type of main ingredients (Table 1).

Myeolchi-jeot (anchovy *jeot*): Produced from anchovy and *saeujeot*, which is made with shrimp, are the most popular *jeotgals* in Korea. Depending on the harvesting season, both *jeotgals* are often called *choonjeot* (春醃) from anchovy harvested in spring and *chujeot* (秋醃) in autumn [44]. Fresh anchovies, harvested from the south coast of Korea, are washed, drained, and salted by layering with anchovy and salt, alternately. The salt concentration

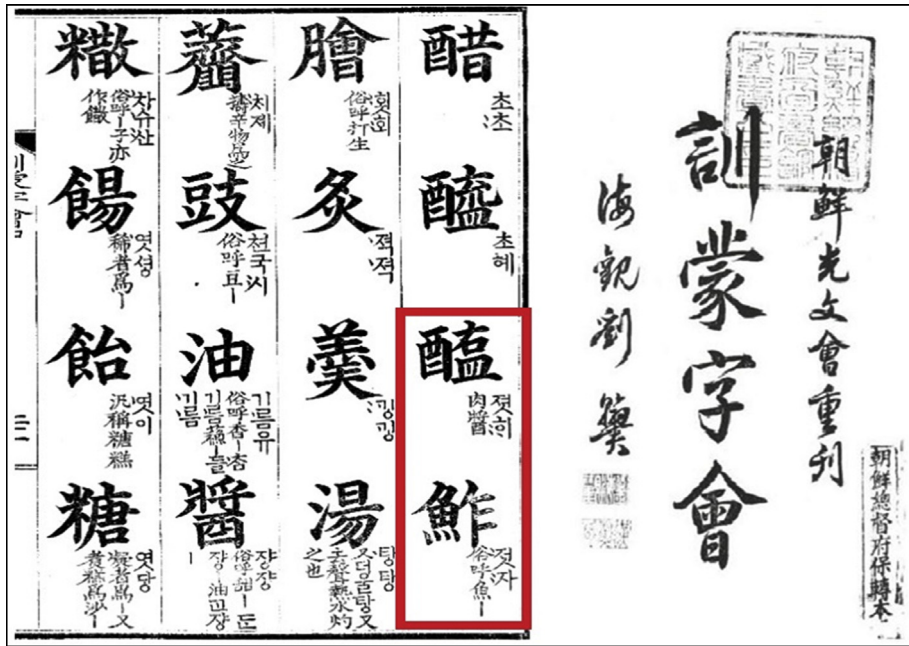


Fig. 4. Chinese characters (鮓 and 醃), which represent jeot or jeotgal in Hunmongjahoe (訓蒙字會) by Choi (崔世珍) [18]. Ja (鮓) and hae (醃) represent jeotgal (fermented fish product) in Cheminyosul (齊民要術) and others literature (醃).

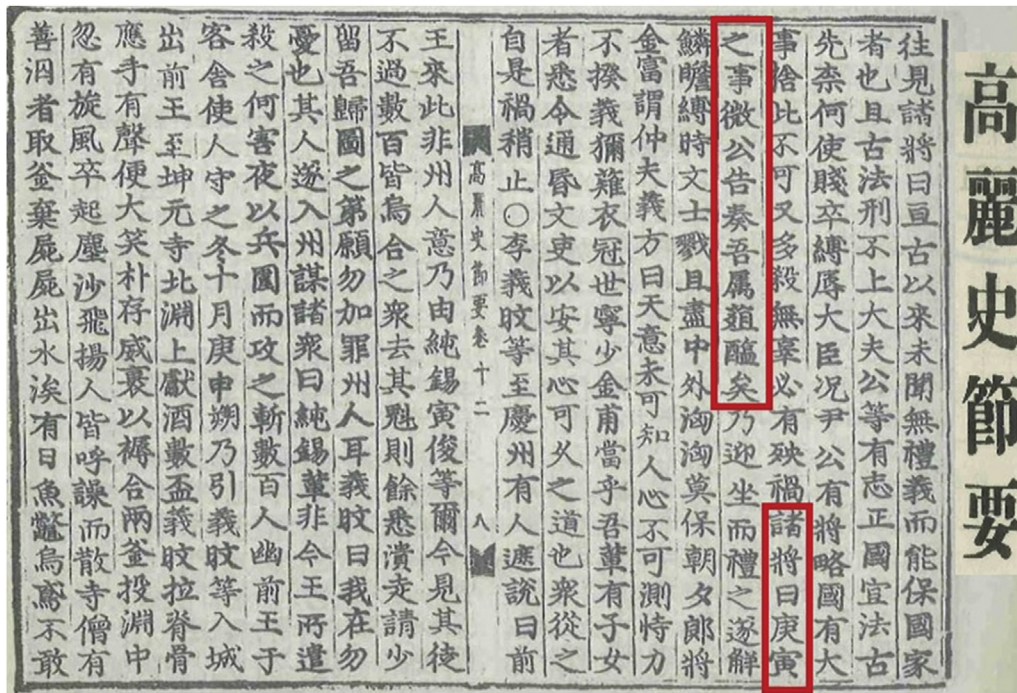


Fig. 5. Expression about cruel way to kill people by tearing the body as kimchi and jeotgal. tearing. Korosajeolyo (高麗史節要) (1173). Many commanders say that if you did not tell Jin (金) dynasty (1115–1234) about what happened in 1170 (庚寅年), we would have been executed and our body would have been torn out like as jeot or kimchi and salted (諸將曰庚寅之事微公告奏吾屬道醃矣).

is ~20–30% w/w and qualified refined salt is used. The fermentation period is ~2–3 months depending on the salt concentration and temperature [45]. Fresh shrimp for saeujeot are harvested from Yellow Sea, the west and southwest coast of Korea. Since the shell is hard for salt infusion into the meat, a higher concentration of salt is necessary, by 35–40% in summer and ~30% in winter. Fresh shrimp is washed with sea water or 3–4% salted water then

quality refined salt is added and stored for 4–5 months at 13–20°C [42].

Other parts or intestines: Jeotgal that is made with gills (agami in Korean) is rich in calcium. About 15–20% of refined salt is added to the washed gills and it is fermented for up to 3 months with the addition of seasonings. Since salt infusion rate is slow in gills, it is important to incorporate with salt and other ingredients [46]. Other

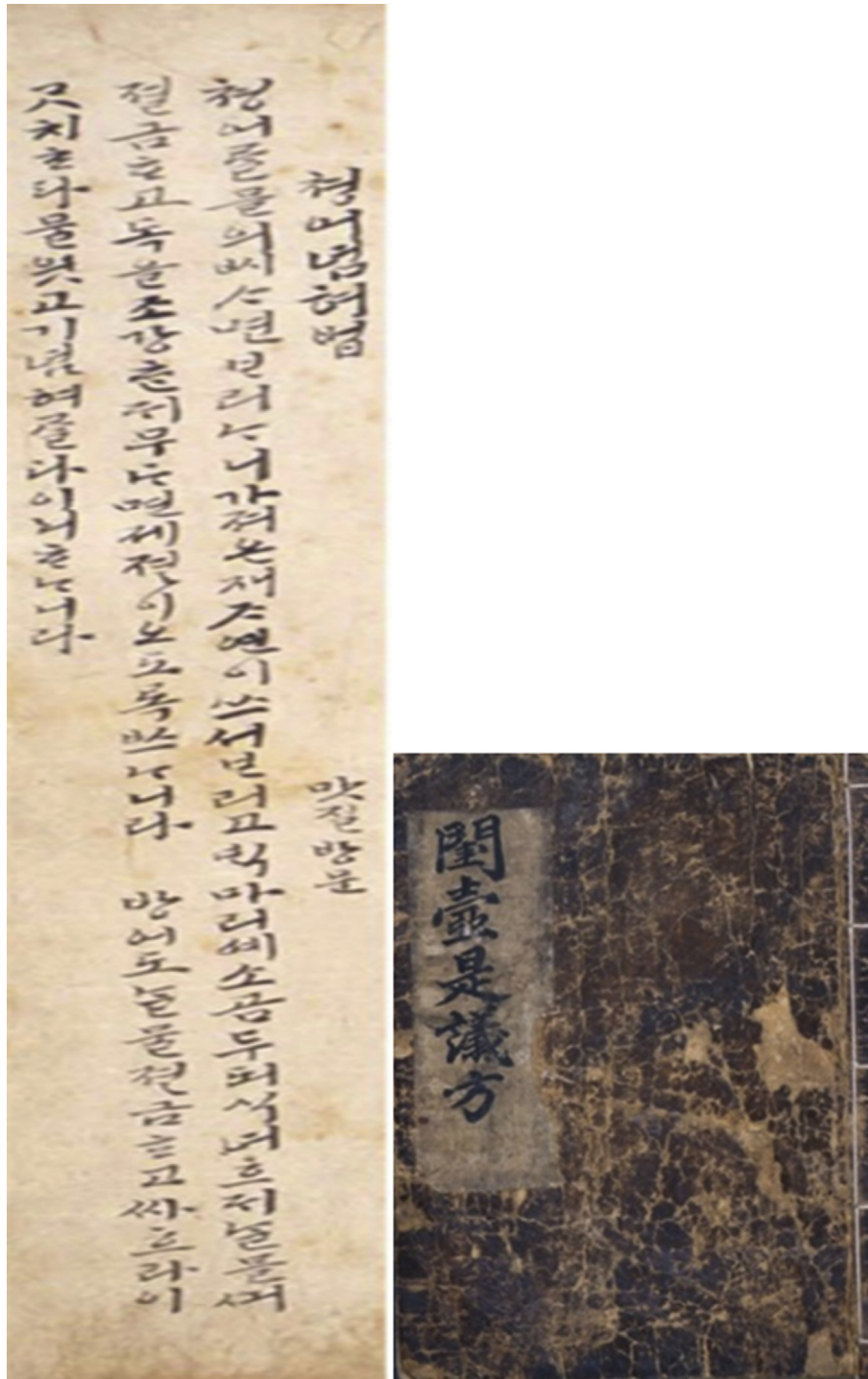


Fig. 6. Eumsikdimibang (閩臺是議方, one book of recipe for Korean food described in Hangul) describes the preparing method for chonggeojeot (herring jeot) in detail.

parts of the fish or shellfish such as intestine and roe (*al* in Korean) are used to produce special *jeotgal*. In order to provide their unique texture and flavor, it is important to remove the whole intestine or roe without cut.

Hongeo: A very special fish, skate has a completely different flavor from other fermented fish products, and can be classified as *hongeo-jeot*. However, unlike other *jeotgal*, *hongeo* is not named as *hongeojeot* because it was recognized as nutritious main dish rather than seasoning or condiment [15]. This is the reason for *hongeo* not being

included in Table 1. Skate contains high protein with low fat and glutamic acid (14.7%) aspartic acid (9.59%) and it also contains 22.8% of essential fatty acids such as linoleic acid, linolenic acid and arachidonic acid [15]. It has a very strong pungent order and taste due to the ammonia in the skate. In order to control the osmotic pressure, skate contains 100 times more urea than humans and the urea is converted to ammonium during fermentation. It is often said, “Do not discuss on Korean foods or tastes until you taste *hongeo*”. Because of the ammonia, microorganisms cannot grow to be highly preservative. Skate is

Table 1
Classification of *jeotgals* based on the main ingredients.

Type of main ingredients	Food products (main ingredients)
Whole fish & shellfish	
Fish	Order Clupeiformes: <i>myeolchijeot</i> (anchovy), <i>baendaengijeot</i> (herring), <i>jeoneojeot</i> (gizzard shad), <i>jeongeoriyeot</i> (sardine), <i>junchijeot</i> (Chinese herring), <i>euneojeot</i> (<i>Coilia nasus</i>), <i>yeobsakjeot</i> (gizzard shad), <i>duiporijeot</i> (herring) Order Perciformes: <i>kalchijeot</i> (cutlass fish), <i>chokijeot</i> (croaker), <i>whangseojeot</i> (yellow corvina), <i>godeungeo jeot</i> (mackerel), <i>kanari jeot</i> (sand eel), <i>mineo jeot</i> (croaker), <i>nungsungeo jeot</i> (convict grouper), <i>domi jeot</i> (sea bream), <i>maegari jeot</i> (horse mackerel), <i>byungeo jeot</i> (pomfret) Others: <i>bollackjeot</i> (rockfish), <i>kajamijeot</i> (flatfish), <i>kongchi jeot</i> (saury), <i>taegu jeot</i> (cod), <i>baemjangeo jeot</i> (eel), <i>dongtae jeot</i> (frozen pollock), <i>bangeo jeot</i> (icefish)
Crustaceans	Shrimps: <i>saeujeot</i> (small shrimp), <i>gonjangijeot</i> (mysidacea), <i>kaetgajae jeot</i> (squilla), <i>daeha jeot</i> (jumbo shrimp) Crabs: <i>tulge jeot</i> (hairy crab), <i>bangke jeot</i> (3-spined shore crab), <i>kotge jang</i> (blue crab), <i>dolge jang</i> (stone crab), <i>chamge jeot</i> (Chinese mitten crab)
Mollusks	Class Cephalopoda: <i>ojingeojeot</i> (squid), <i>koltukijeot</i> (small squid), <i>nakji jeot</i> (small octopus), <i>hanchi jeot</i> (cuttlefish) Class Bivalvia: <i>kuljeot</i> (oyster), <i>eorikul jeot</i> (oyster with hot pepper), <i>bajirak jeot</i> (clam), <i>dongjuk jeot</i> (surf clam), <i>daehap jeot</i> (clam), <i>matjeot</i> (razor clam), <i>moshijogae jeot</i> (short-necked clam), <i>baekhap jeot</i> (large clam), <i>pijogae jeot</i> (ark clam), <i>honghap jeot</i> (mussel) Others: <i>obunjaki jeot</i> (supertexta), <i>sora jeot</i> (conch)
Internal parts of seafood	
Gills (<i>agami</i>)	<i>Taegu-agami jeot</i> (cod), <i>mineo-agami jeot</i> (croaker), <i>myeongtae-agami jeot</i> (pollack), <i>jogi-agami jeot</i> (yellow corvina)
Intestine	<i>Chang-nan jeot</i> (pollack), <i>haesam-changja jeot</i> (sea cucumber), <i>kodeungeo-changja jeot</i> (mackerel), <i>kalchi-sok jeot</i> (cutlass fish), <i>chuneobam jeot</i> (gizzard shad), <i>jogi-sok jeot</i> (yellow corvina), <i>chunboknae-jang jeot</i> (abalone), <i>baemjangeo-chang jeot</i> (eel)
Roe (<i>al</i>)	<i>Myeong-ran jeot</i> (pollack), <i>gealjeot</i> (crab), <i>godeungeo-al jeot</i> (mackerel), <i>taegu-al jeot</i> (cod), <i>saeu-al jeot</i> (small shrimp), <i>sungke-al jeot</i> (sea urchin), <i>sungeo-al jeot</i> (mullet), <i>yuneo-al jeot</i> (salmon)

3.2. Classification by seasoning

Jeotgal: Most traditional *jeotgal* was simply prepared by adding salt and fermenting and maturing for a certain period by based on documents in *Cheminyosul* (齊民要術) [2,39–41] or other old literature for > 1,000 years.

Seasoned jeotgal: However, as shown in Table 2, other *jeotgals* were fermented with Korea red peppers [47], cooked grains, soy sauce (*kanjang*) [4], and/or malted rice, in addition of salt. Some others spices are also added to provide additional flavor to *jeotgal*. This method is almost similar to the procedure of an old book, *Kyuhapchongseo* (閩閩叢書) [40]. Oyster is easy to ferment due to the high content of glycogen, so that only 10% of salt is added and fermented for ~1 week for low salted oyster product. Regular oyster *jeotgal* (*kuljeot*) adds ~20% of salt with a 1-month fermentation period. *Eorikuljeot* is famous for the addition of Korean red pepper and other spices such as garlic, ginger, relish, and scallion [48]. Most mollusks including squids and octopuses are processed by removing internal organs and bones and are fermented with Korean red pepper, garlic, ginger, syrup, and other seasonings. A similar procedure was recorded in the methods of old literature [39–41]. *Changnanjeot* is manufactured using intestine and eggs of pollock, which provides unique chewy texture to the *jeotgal*. It is usually consumed with addition of seasoning including red pepper, ginger, and sesame. The roe of pollock is also used for the production of *jeotgal*, named

Table 2
Classification and characteristics of *jeotgals* by manufacture process.

Type	Main ingredients	Spices
<i>Jeotgal</i>	Fish, shellfish, intestine	Salt
Seasoned <i>jeotgal</i>	Fish, shellfish, intestine	Salt, seasoning (hot pepper, garlic, ginger, green onions)
<i>Aekjeot</i>	Fish, crustaceans, residual products	Salt
<i>Sikhae</i>	Fish, mollusks, roe	Salt, cooked grains, seasoning, malt, radish

myeongranjeot. Natural coloring agents such as monad red, annatto, β -carotene, and beet red are added in the roe with other additives, lactic acid, succinic acid, glycine, and spices such as hot pepper, garlic, ginger, and sesame, sugar [11].

Aekjeot: Fermented fish sauce, *aekjeot* (liquid *jeot*), can be made by most of seafood ingredients. The main principal of manufacturing process is very similar to *jeotgal*; however, fermentation period is much longer than *jeotgal*. For example, anchovy *aekjeot* is fermented for 6–7 months and the liquid formed during the fermentation is called *sangjeot-kuk*.

Sikhae (食醃): *Sikhae* was written in an old book, *Cheminyosul* [2] and many books of *The Annals of the Chosun Dynasty* (朝鮮王朝實錄) [33,34] as a favorite fermented fish product, and is a cured fermented fish with cooked grains. Cooked grain, malt, hot pepper, and others are mixed with the salted seafood and fermented. There are different varieties of *sikhae* by the type of grains or the combination of the ingredients, depending on the region. For example, eight different combinations of cooked grains (rice, glutinous rice, flour, millet), salt, seasonings (Korean red pepper or malt), and radish (presence or absent) are known [49]. Any decomposed byproducts from the subingredients enhance the flavor of salted seafood. As for fermented fish sauce, any seafood for *jeotgal* can be used for *sikhae* and the *jeotgal* itself can also be used [6]. *Kajami-sikhae* (flat fish *sikhae*) is the most popular *sikhae*, especially in North Korea before the Korean War (1950), which is made with flat fish and ~5–10% of refined salt is added. After ~1 day of salting, other subingredients are added with 20–50% w/w and cured for ~2 weeks. Because preservation period is limited by 1–2 weeks, it is produced during autumn and winter [42].

4. Microbial community of *jeotgal*

Microorganisms naturally come from the main ingredients such as seafood, spices, and vegetables depending on the type of *jeotgal*, and also from the environments such as seawater, marine mud, and even from the handlers [50]. Because of the high sodium content in *jeotgal*, growth of most harmful microorganisms is inhibited due to the increasing osmotic pressure and decrease in water activity for

the preservation. However, the ripening of *jeotgal* is not only by autolysis of the meat and offal of fish but also the microbial activity during fermentation. The microorganisms that survive and are involved in fermentation are halophilic or halotolerant. As there are hundred types of *jeotgal* depending on the ingredients and fermentation methods, microbial communities also differ by the ingredients and duration of the fermentation.

Most commonly, *Bacillus*, *Brevibacterium*, *Flavobacterium*, *Micrococcus*, *Pediococcus*, *Pseudomonas*, and *Staphylococcus* are frequently isolated from various *jeotgal* products along with halophilic and halotolerant bacteria such as *Halobacterium* and *Halomonas* [51–53]. During fermentation, bacterial community succession from Proteobacteria to Firmicutes has been monitored and is considered to be a common indicator for *jeotgal* [50].

The microbial community in *myeolchijeot* (anchovy) was monitored during fermentation periods and in the early part of fermentation, *Pseudomonas*, *Acinetobacter*, *Flavobacterium*, and *Brevibacterium* were common. In the intermediate period, *Halobacterium*, *Pediococcus*, *Sarcina*, and *Micrococcus* in bacteria and *Saccharomyces* and *Torulopsis* in yeast were isolated and especially *Pediococcus* and *Saccharomyces* were the most dominant microorganisms. As the fermentation proceeds, the microbial population decreased, however *Halobacterium*, *Cutirubrum*, *Micrococcus morrhuae*, *Sarcina litoralis*, and *Pediococcus cerevisiae* were identified throughout the fermentation process of *myeolchijeot* [45]. In another study, most of the isolates in *myeolchijeot* belonged to class Bacilli, including genera *Bacillus*, *Rummeliibacillus*, *Sporosarcina*, *Virgibacillus* as well as *Halomonas*, *Kocuria*, and *Psychrobacter* [53].

Saeujeot (small shrimp *jeot*) contained large number of halophilic bacteria such as *Halomonas*, *Salinicoccus*, *Salinimicrobium*, *Salinivibrio*, and *Staphylococcus*, and *Lactobacillus*, *Leuconostoc*, *Psychrobacter*, and *Weissella* were also isolated [53]. *Ojingeo-jeot* (squid *jeot*) is dominated by *Bacillus*, *Staphylococcus*, and *Weissella*, and *Carnobacterium*, *Leuconostoc*, and *Pediococcus*, and others were also isolated [54].

Until recently, culture-dependent methods have been the primary tools to investigate the microbial community, however culture-independent methods were developed and are recognized as an important tool to show more diverse and complex microbial communities. Therefore, recent studies on the microbial communities in *jeotgals* were also performed with molecular methods such as pyrosequencing analysis with 16S rRNA genes. Roh et al [50] investigated archaea and bacterial communities of *saeujeot* (small shrimp), *jokaejeot* (shellfish), *kapojingoe jeot* (cuttlefish), *kuljeot* (oyster), *myeongranjeot* (pollock roe), *changranjeot* (pollock tripe), and *kejeot* (crab; see above in History). Depending on each *jeotgal*, the communities were diverse, while mostly composed of halophilic and mesophilic groups. In the family Halobacteriaceae, halophilic archaea such as *Halorubrum* and *Halalkalicoccus* were dominant in most *jeotgals*, while uncultured mesophilic Crenarchaeota were identified in *kapojiingoe jeot* (cuttlefish). Lactic acid bacteria including *Lactobacillus* and *Weissella* were over 90% of all bacterial sequences in *saeujeot* (shrimp), *changranjeot* (pollock tripe), *myeongranjeot* (pollock roe), and *kejeot* (crab). *Jogaejeot* (shellfish) was dominated by Gammaproteobacteria (mostly *Salinivibrio*), while oyster contained genus *Lactobacillus* followed by family Alphaproteobacteria (*Rhizobiales*), Gammaproteobacteria, and then *Weissella* [49].

The microbial population in *ojingeo jeot* (squid) was also investigated by pyrosequencing method and it was predominated by genera *Leuconostoc* (*Leuconostoc citreum* and *Leuconostoc holzapfelii*), *Bacillus*, *Staphylococcus*, *Psychrobacter*, *Paracoccus*, *Kocuria*, and *Micobacterium*. Along with the microbial community analysis, this group also tested the prevalence of osmotic stress-related genes. While *Leuconostoc* did not possess genes homologous to

the osmotic stress-related genes, all other genomes showed the presence of the genes [55].

The microbial community of *sikhae* was also tested by number of researchers. *Sikhae* showed totally different microbial community compared to *jeotgal*, potentially due to the subingredients and the manufacture process. In *myeongtae sikhae* (Alaska pollock), *Lactobacillus sakei* was only 2% before the fermentation, but *L. sakei* was dominated by 74% at 10°C and 90% at 20°C. *L. sakei* is psychrotrophic, salt tolerant, and bacteriocin producer, which could be critical for decrease of unpreferred bacterial species during fermentation [56]. *Kajami-sikhae* was also shown to contain *L. sakei* as the most abundant species. Others such as *Lactobacillus graminis*, *Lactobacillus alimentarius*, *Lactobacillus fructivorans*, and *Weissella thailandensis* were also observed. Overall, over 90% were dominated by Leuconostocaceae and Lactobacillaceae families in *kajami-sikhae* [57]. *Sikhae* is produced by cooked grains, hot peppers, and other spices. White radish is also added to *sikhae* and interestingly, the white radish in *kajami sikhae* reduced the level of Proteobacteria from ~10% relative abundance to almost zero rate. When white radish was added to *kajami sikhae*, *Lactobacillus* presented 89–91% relative abundance and the rest was dominated by *Weissella* [58].

Jeotgal is rich in microorganisms that are yet to be cultured or identified. As *jeotgal* is produced by different marine animals from different regions and different fermentation conditions, *jeotgal* can contain varieties of microorganisms. Therefore, several novel microorganisms have been also isolated and identified. *Jeotgalicoccus* was the first identified genus and is the most closely related to *Salinicoccus* [59]. *Proteus cibarius* sp. nov. [60], *Weissella jogae-jeotgali* sp. nov. [61], *Brevibacterium jeotgali* sp. nov. [62], *Halomonas cibimaris* sp. nov. [63], *Kocuria atrinae* sp. nov. [64], *Paenibacillus tyraminigenes* sp. nov. [65], *Salinicoccus jeotgali* sp. nov. [66], and a number of other novel bacteria have been identified.

With the high prevalence of lactic acid bacteria in *jeotgal*, the probiotic potential of the isolates had also been studied. Lactic acid bacteria and yeasts isolated from commercial *jeotgals* including *ojingeojeot* (squid), *koltugijeot* (small squid), and *myeolchijeot* (anchovy) showed resistance to artificial gastric and bile juice and antimicrobial activity to *Listeria monocytogenes* [67]. *Pediococcus pentosaceus* from *saeujeot* was able to survive at pH 3.0, and 0.3% bile salts, and adhered to Caco-2 cells [68]. *Lactobacillus plantarum* NK181 also showed resistance to pH 2.5 and bile salt, adherence to Caco-2 cells, and 1,1-diphenyl-2-picryl hydrazyl (DPPH) radical-scavenging activity and cholesterol reduction activity [69]. *Lactococcus lactis* NK34 additionally showed the production of interleukin-1 α and inhibition of the formation of preneoplastic lesions [70].

5. Functionality of *jeotgal*

Enzymatic autolysis of tissue digestive enzymes in the organs induces the breakdown of complex compounds (such as carbohydrates, fats, and protein) of the tissues to oligomers or monomers such as peptides, free amino acids, glucose, and vitamins. *Jeotgal* is rich in essential amino acids such as lysine and threonine and also provides umami flavor by natural glutamic acid, alanine, and glycine [46]. *Jeotgal* increases the appetite, protects liver and is a great source of vitamin B. In addition, *jeotgal* can be a good digestant because of its high protease content. *Saeujeot* (small shrimp) is consumed as a dipping sauce for meat products to ease the digestion [71].

The health benefits of *jeotgal* increase as the fermentation proceeds with the conversion of phytochemicals and/or with the increase in functional byproduct. During fermentation of *saeujeot* (small shrimp), free amino acid content increased in twice after 72 days. Essential amino acids such as lysine, glutamic acid,

methionine, alanine, aspartic acid, and leucine showed 1.27–5.79-fold increase after 72 days of fermentation [72].

Myeolchijeot (anchovy *jeot*) is one of the important subingredients for *kimchi* [14]. Fermented *myeolchijeot* can prevent somatic mutation and has anticancer activity while fresh anchovy with salt causes mutations in *Drosophila*. *Meyolchijeot* fermented for 6 months and 12 months shows 26.6% and 43.4% antimutagenetic activity, respectively [73]. Lim et al [74] evaluated the cell viability of liver hepatocellular carcinoma cell HepG2 among commercial *jeotgal* and *chuneobamjeot* (shad gizzard) resulted in the strongest activity by 77.6% followed by *kajami-sikhae* (flat fish), *ojingeojeot* (squid), and *koltugijeot* (small squid). As shown, *sikhae* showed stronger anticancer activity due to the highly bioactive grains and other subingredients such as garlic and hot pepper to increase the health function [75,76].

Antioxidant substances can be mostly extracted from plants including fruits and vegetables as phenolic compounds, while it is rare in animals. However, there have been reports on antioxidant peptides from animal proteins by enzymatic hydrolysis, which includes *myeolchi-aejkjeot* (anchovy sauce) [77]. In particular, bio-compounds such as glutamic acid and lysine showed stronger anticancer activity than fermented soybean products, *doenjang* and *chongkukjang* and the longer the fermentation, the stronger the antioxidant activity observed [77]. *Whangseokeo-jeot* (yellow corvina) showed increased radical scavenging activity and reducing power during fermentation potentially due to the carbonyl compounds formation during the Maillard reaction [78]. Other research showed the presence of angiotensin-converting enzyme inhibitors in *myeolchi-jeot* (anchovy), which contained high amount of threonine, glutamic acid, lysine, serine, and proline [79]. High conjugated linoleic acid, especially *cis* 9-, *trans* 11-conjugated linoleic acid production was monitored by *Lactobacillus paraplantarum*, *L. plantarum*, *Lactobacillus pentosus*, and *Leuconostoc mesenteroides* isolated from *ojingeojeot* (squid), *jokaejeot* (scallop), *kuljeot* (oyster), *changranjeot* (pollock roe), and others.

Until now, a high concentration of salt has been added to *jeotgal* for preservation [80]. However, due to the increase in awareness of health and change in appetite, demand for low sodium *jeotgal* is increasing. Low sodium *jeotgal* not only reduced the salt concentration, but also adds a variety of herbs to prolong the storage time, and increase the quality and functionality. In addition, *jeotgal* has a great potential to be a nutritious and palatable food by low sodium *jeotgal* production.

6. Conclusion

The Korean traditional fermented fish product, *jeotgal*, is a brilliant descendant from our ancestors for the best preservative method of fish and shellfish from deterioration. Along with the historical research, metagenomic and metabolomic research and the research on the probiotic lactic acid bacteria from *jeotgal* have shown the needs on the development of this high value added food product. *Jeotgal* has shown to be a potential bioactive functional food by anticancer, antioxidant, antidiabetics, growth promoter, decrease in body fat, and immune-boosting activities. Until now, a high concentration of salt has been added to *jeotgal* for preservation. However, due to the increase in awareness of health and change in appetite, demand for low sodium *jeotgal* is increasing. With the addition of variety of herbs to substitute sodium and prolong the storage time, we should be able to increase the quality and functionality. Therefore, the efforts on research and development of *jeotgal* based on the consumers' demand shows that *jeotgal* has a great potential to be recognized as a nutritious and palatable food product globally.

Conflicts of interest

All authors have no conflicts of interest to declare.

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