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Health benefits and functions of salt-fermented fish

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Abstract

Salt-fermented fish, a typical food in many regions of the world, was classified into three types depending on the processing method. It was divided into a process of fermenting by adding fish and salt only, a method of filtering it to form a fish sauce, and a method of lactic acid fermenting by adding additional carbohydrates. The free amino acids produced in large quantities through fermentation make salt-fermented fish a valuable protein source in regions where rice is the staple food. Furthermore, they also have significant amounts of omega-3 fatty acids (EPA and DHA), making them nutritionally excellent and functional, with antioxidant, antihypertensive, and fibrinolytic activities that benefit cardiovascular health. Some lactic acid bacteria (LAB) isolated from fermented fish products have beneficial effects on humans, including bacteriocin and probiotic effects. Looking to the future, the potential benefits of reducing naturally occurring biogenic amines and adjusting the salt content for storage stability could further enhance the health and taste benefits of salt-fermented fish, providing hope and optimism for the future of food preservation and nutrition.

Keywords Salt-fermented fish, Nutrition value, Health benefits, Biogenic amine

Introduction

Fermentation, an ancient method of food preservation, is a cost-effective means to extend the shelf life of highly perishable fish while enhancing flavor and nutritional quality [1]. Rooted in history since around 6000 BC, humans salted seafood using earthenware vessels, triggering natural fermentation by salt-tolerant bacteria and shaping salting and fermentation technology [2]. The historical significance of fermented fish, a practice transcending time and cultures, is evident in ancient Greece, where it became a vital Mediterranean trade commodity [3]. This rich cultural heritage adds a layer of appreciation to the nutritional and health benefits of salt-fermented fish.

Fish fermentation relies on endogenous autolytic enzymes, predominantly pepsin and trypsin, complemented by associated microflora, with the process influenced by the chosen fermentation method [1]. In the presence of salt, spoilage microorganisms cease activity, allowing the fish's autolytic enzymes to hydrolyze proteins, lipids, and carbohydrates, creating characteristic flavors [1]. When bacteria participate, organic acids like acetic and lactic acid form, resulting in easily digestible and nutritious fermented fish products [4, 5]. These products smoothly integrate into diets globally, serving as seasonings or supplementary ingredients across Asia, Africa, Europe, and Mediterranean regions [6].

Southeast Asia, a region with rice as a staple food, embraces salted fish as a traditional fermented food, meeting dietary needs for sodium and protein [3]. In Korea, a grain-culture area, health concerns arise due to high sodium intake from salt-fermented fish alongside kimchi, soybean paste, and soy sauce [7]. Extensive

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studies have explored the nutritional value of salt-fermented fish, such as antioxidants, antibacterial properties, antihypertensive effects, anti-thrombotic benefits, anti-obesity potential, immune enhancement, osteoporosis prevention, and skin whitening [1, 3, 6, 8, 9]. Salted fish containing γ-aminobutyric acid (GABA) and a thrombolytic enzyme from *Bacillus* bacteria is reported to aid in preventing cardiovascular diseases [1, 9, 10].

This review comprehensively explores fermented fish processing methods, regional distributions, the diverse health benefits of nutritional and functional characteristics, and biogenic amines related to food hygiene.

Fermentation types of salt-fermented fish around the world

Numerous traditional fermented fish products exist worldwide, including in Asia, Africa, and Europe. Although the primary method for all fermented fish products involves the use of high amounts of salt, differences exist in the choice of raw materials, fish-to-salt ratio, duration of fermentation, and addition of other raw materials during the fermentation process.

Fermented fish products can be divided into three groups depending on the fermentation type shown in Table 1. The final product appearance is (1) a product consisting of whole, small pieces of meat or viscous paste, such as *rakfish* (Norway), freseekh (Egypt), *ngari* (India), *ngapi* (Myanmar), *bagoong* (Philippines), *pra-hoc* (Cambodia), *pla-ra* (Thailand), *belacan* (Malaysia); (2) a fish sauce (used as liquid with more or less viscosity), such as *nuoc-mam* (Vietnam) or *nam-pla* (Thailand), *bakasang* (Indonesia), *shottsuru* (Japan), *aek-jeot* (Korea); or (3) fish lacto-fermented with a source of carbohydrates (cooked rice, vegetables, millet and malt as a starter), such as *plaa-som* (Thailand), *phaak* (Cambodia), *narezushi* (Japan), and *sikhae* (Korea).

Fermenting whole or large pieces of fish results in the fish retaining as much as possible of its original structure [6, 11]. Fermented fish pastes, where the fish is converted into paste-like products [12], and fish sauce, which is completely converted into a liquid form [13]. Based on processing methods, fermented fish can be divided into two classifications: fermentation using fish and salt only. Second, fermentation uses fish, salt, and carbohydrate, including cooked rice, millet, and flour [6]. In fermented fish products using fish and salt, for example, *rackfish* is a native fish dish of Norway made from salmonid freshwater fishes (trout or char) and 4–6% salt [6]. *Feseekh* of Egypt is mainly made of pebbly fish (*Alestes baremose*) and 20–30% salt [14]. *Surströmming*, having a unique smell, is a fermented fish product made from herring in Sweden [6]. *Lanhouin* is made from whole cassava fish (*Pseudotolithus senegalensis*), a traditional fermented salted fish condiment in West African countries [15]. *Ngari* is a fermented fish product of Manipur in North-East India and is usually eaten as a side dish with cooked rice [16]. *Jeotgal*, known as salt-fermented seafood in Korean cuisine, adds 5–30% (w/w) salt to raw materials such as shrimp, shellfish, and fish [9].

Even in Southeast Asia, many salt-fermented fish products that use the whole fish body or are in paste form are being introduced. For example, the *ngapi-gaun* of Myanmar is made by adding 30% salt to catfish and maturing it for about a month [1]. *Bagoong* is a fermented product made by adding 30% salt to fish such as sardines, mackerel, and anchovies and maturing them for 2–6 months [11]. Meanwhile, *prahok* is a salt-fermented fish paste that uses carp as a raw fish, and it is favored in Cambodian cuisine as a seasoning or condiment [11]. Fish paste made from freshwater fish, such as *pla-ra*, is also used in Thailand [1, 9]. Salt-fermented fish products such as *terasi* of Indonesia, *kapi* of Thailand, and *belacan* of Malaysia are made from shrimp as a paste [1, 11].

Fish sauce is traditionally produced by using whole fish with salt in a ratio of 1:1 to 3:1 and fermenting anywhere between 6 and 12 months or even longer [17]. The fermented liquid is rich in fish-soluble proteins, peptides, and amino acids characterized by umami tastes [18]. Different names in different countries are used to describe these sauces. In Vietnam, it is called *nouc-mam*; in Thailand, it is called *nam-pla*. The others, including *budu* of Malaysia and Indonesia, patis of the Philippines, *bakasang* of Indonesia [19], *yu-lu* of China [20], *shottsuru* of Japan, and *aek-jeot* of Korea have been popularly used throughout the Asian region. *Colatura di alici* is a traditional anchovy sauce produced in Campania, Italy [21]. Fish sauces generally contain all essential amino acids, vitamins, and minerals [6]. Nowadays, Southeast and East Asian countries are the leaders in their fish sauce production and have annually expanded into international markets [6].

Other fermented fish products using fish, salt, and carbohydrates, including cooked rice, millet, and malt, have been widely used in Asia, as shown in Table 1. For example, *plaa-som* of Thailand is a fermented fish for which whole fish or fish fillets are mixed with salt (8:1; fish: salt ratio, w/w), cooked rice, and minced garlic [6]. Sometimes, cooked rice and garlic are replaced with palm syrup and roasted rice [22]. *Pekasam* of Malaysia is a fermented fish product prepared by mixing freshwater fish with salt (below 10%) and ground, roasted, uncooked rice in 2–4 weeks of fermentation [23]. The fermented fish products, *phaak* of Cambodia, *bulong-isuda* of the Philippines, and *mam chua* of Vietnam, were produced using freshwater fishes or marine fish using similar methods in Southeast Asia [11]. *Narezushi* and *fish-nukazuke*

Table 1 Salt-fermented fish products around the world

Fermentation type	Name	Final product appearance	Raw materials	Salt amounts and fermentation time	Country	References
Products fermented using fish (or crushed fish) and salt only	*Rakfish*	Whole (slice)	Salmonid, Trout	> 5% salt, 9–10 weeks	Norway	[6, 8]
	Feseekh	Whole (slice)	Pebbly fish (*Alestes baremose*), tiger fish (*Hydrocynus* sp.)	20–30% salt, 60 days	Egypt	[6]
	Surströmming	Whole (slice)	Baltic herring	17% salt, 1–2 months	Sweden	[6, 8]
	Ngari	Whole (slice)	*Puntius* spp.	0 salt, 6–12 months	India	[68]
	Lanhouin	Whole (slices)	Cassava fish, Spanish mackerel	15–35% salt, 3–8 days	Ghana	[3, 6, 105]
	Jeotgal	Whole (slice)	Marine fish, shrimp, shellfish	5–30% salt, 2 months or a few years	Korea	[9]
	Ngapi-gaun	Whole	Catfish	30% salt, 1 month	Myanmar	[1]
	Bagoong	whole	Sardine, horse mackerel, anchovy	30% salt, 2–6 months	Philippines	[11]
	Pra-hoc	Paste	Carp (trey riel, trey lenh)	10% salt, 1 month	Cambodia	[11]
	Man-ruoc (Mam-tom)	Paste	Shrimp	20–30% salt, 1–12 months	Vietnam	[11]
	Terasi	Paste	Shrimp	0.4–10% salt, 2–4 days	Indonesia	[11]
	Pla-ra	Paste	Freshwater fish	17–20% salt, 1–4 months	Thailand	[9]
	Kapi	paste	Shrimp	14% salt, 6 months	Thailand	[1, 8]
	Belacan	Paste	Shrimp	5% salt, 2–5 months	Malaysia	[11]
Products fermented using fish and salt and then filtrated	*Colatura di alici*	Sauce	Anchovy	20–25% salt	Italy	[3, 21]
	Nuoc-mam	Sauce	Anchovy (ca com, cá nuc)	10–15% salt, 8–12 months	Vietnam	[1, 8, 11]
	Nam-pla	Sauce	Anchovy	> 20% salt, 5–12 months	Thailand	[6, 8, 11]
	Budu	Sauce	Anchovy	20–30% salt, 3–12 months	Malaysia, Indonesia	[6, 11]
	Patis	Sauce	Anchovy (dilis, tuakang, kabasi, tunsoy)	22–26% salt, 3–12 months	Philippines	[6]
	Bakasang	Sauce	Sardines	10–20% salt, 40 days	Indonesia	[6, 19]
	Yu-lu	Sauce	Anchovies	30% salt, 6 months	China	[20]
	Shottsuru	Sauce	Sandfish, sardine, sand lance	> 20% salt, 1–3 years	Japan	[11]
	Aek-jeot	Sauce	Anchovy, sand lance	25–30% salt, 1–3 years	Korea	[9]
Products fermented using fish, salt, carbohydrate, and starter	*Plaa-som*	Whole (slices)	Pool barb (*Puntius sophore*), cooked rice, garlic, palm sirup	> 7% salt, 1 week	Thailand	[6]
	Pekasam	Whole (slices)	Freshwater fish (carp), roasted, uncooked rice	> 10% salt, 2–4 weeks	Malaysia	[23]
	Phaak	Whole (slices)	Freshwater fish, cooked rice, malt	< 30% salt, 1–2 months	Cambodia	[11]
	Burong-isuda	Whole (slice)	Fish (marine, freshwater), shrimp, cooked rice, malt	< 5% salt, 1–2 weeks	Philippines	[11]
	Mam chua	Whole (slices)	Freshwater fish, cooked rice	3 weeks	Vietnam	[11]
	Narezushi	Whole (slices)	Carp, mackerel, cooked rice	20–30% salt, 2–3 months	Japan	[6]

Table 1 (continued)

Fermentation type	Name	Final product appearance	Raw materials	Salt amounts and fermentation time	Country	References
	Fish-nukazuke	Whole (slices)	Mackerel, sardine, cooked rice	10–15% salt, 12 months	Japan	[25]
	Sikhae	Whole (slices)	Flat-fish, Alaska pollack, squid, cooked millet	5–10% salt, 1–4 weeks	Korea	[26]

are salt-fermented fish using carp, mackerel, and sardine with rice bran and cooked rice and are very popular in Japan [6, 24, 25]. *Sikhae*, made from various fish species such as flat-fish, Alaska pollack, and squid, is a representative fermented fish product on the East coast of Korea. Malt powder as an additive can enhance the enzymatic degradation of fish and acid and alcohol fermentation by adding carbohydrates such as cooked rice and millet [26, 27].

On the other hand, since salt added to fermented fish is known to increase the risk of hypertension and cardiovascular diseases [27], fish lacto-fermented with a carbohydrate source is considered suitable as a fermented fish product for modern society.

Nutritional values of salt-fermented fish

Free amino acids

Low molecular weight compounds such as soluble proteins, peptides, and amino acids are produced during proteolytic degradation by endogenous proteases in fish muscles or digestive tracts of fish, and various microorganisms exist in fish fermentation [17, 28]. Fish sauce, therefore, is considered an important source of dietary proteins and amino acids and has become a necessity in Southeast Asian households [29].

The compositions of free amino acids in salt-fermented fish products are summarized in Table 2. The total contents of free amino acids ranged from 6815 to 10,223 mg/100 in fish sauce products such as *nam-pla* (Thailand), *nuoc mam* (Vietnam), *patis* (Philippines), *bakasang* (Indonesia), *budu* (Malaysia), *aek-jeot* (Korea), and *ishiru* (Japan) [30, 31]. These fish sauces are fermented using red meat fish such as anchovies, sardines, and sand lances as raw materials, and the total content of free amino acids is thought to vary depending on the fish species and fermentation time. Meanwhile, the amino acid content was relatively low at 1443–5753 mg/100 g in fermented whole fish (or fish paste) such as *jeotgal* (Korea) [32] or *adjuevan* (Ivory Coast) [33] and fish products fermented with carbohydrates such as *narezushi* (Japan) [34] and *sikhae* (Korea) [35]. The content of essential amino acids ranged from 465 to 5010 mg/100 g. However, most fish sauces accounted for more than 50% of total amino acids, and the proportion was particularly high in *patis* (59.3%) and *bakasang* (57.0%). Salt-fermented fish, therefore, are considered to be responsible for the difference. In addition, branched-chain amino acid (BCAA) content, recently known as skeletal muscle synthesis amino acids and playing a very important role in protein metabolism [36], was also present in the range of 1154–1867 mg/100 g in fish sauces, accounting for 16–25% of all free amino acids. However, in *sikhae* made of Alaska pollack, it was very low at 213 mg/100 g, accounting for 14.8% of total free amino acids [35]. Unlike the red meat fish used in fish sauces, white meat fish species and the short fermentation time (within four weeks) are considered to be the effect.

Taurine, detected in considerable amounts in *jeotgal*, *narezushi*, and *sikhae*, has been well known to have several beneficial physiological actions, including antioxidant, detoxification, osmoregulation, cell membrane stabilization, and neuromodulation [37–42]. γ-Aminobutyrate (GABA), a major inhibitory neurotransmitter in the adult mammalian brain, is also present in fermented fish products [43]. Since plant-based foods are also deficient in lysine and methionine, consuming fermented fish containing these will fulfill the amino acid requirements of people with a cereal-based diet [1].

Each amino acid has its unique taste, and Fuke and Shimizu [44] have identified two amino acids, aspartic acid and glutamic acid, as having an umami taste, and five amino acids, threonine, serine, glycine, alanine, and lysine, as having a sweet taste. Additionally, six amino acids, valine, methionine, isoleucine, leucine, phenylalanine, and histidine have a bitter taste [45]. Using this method, the content of sweet taste in fish sauces was highest in the range of 1529–4140 mg/100 g, accounting for 24.6–41.2% of the total free amino acids. Next, the bitter taste ranged from 1737 to 3232 mg/100 g, accounting for 28.4 to 47.4% of the total free amino acids. Moreover, the umami flavor ranged from 982 to 2520 mg/100 g, accounting for 16–25.2% of the total free amino acids. However, the taste threshold of aspartic acid and glutamic acid, which have an umami taste, is 3 and 5, respectively, which is 4 to 100 times lower than that of other amino acids, so when converted to each taste value

Table 2 Free amino acid contents of salt-fermented fish products[1,2]

Amino acid (A.A.)	*Nam-pla* (Thailand)	*Nuoc mam* (Vietnam)	*Patis* (Philippines)	Bakasang (Indonesia)	*Budu* (Malaysia)	*Aek-jeot* (Korea)	*Ishiru* (Japan)	*Jeotgal* (Korea)	*Adjuevan* (Ivory Coast)	*Narezushi* (Japan)	*Sikhae* (Korea)	(mg/100 g) Taste threshold
Aspartic acid	760	1150	560	362	362	710	1059	91	448	506	89	3
Threonine	460	700	482	60	230	456	608	217	162	254	54	260
Serine	360	610	418	465	163	399	585	146	223	333	59	150
Glutamic acid	950	1370	988	727	620	1314	1383	355	745	588	168	5
Proline	230	330	55	0	0	222	423	178	5	27	90	300
Glycine	340	460	328	72	174	278	536	81	112	189	75	130
Alanine	700	1010	687	484	406	654	908	126	342	601	105	60
Valine	590	830	650	476	373	517	745	157	257	377	76	140
Cysteine	0	0	250	277	97	48	0	16		0		
Methionine	230	270	396	360	220	270	261	114	108	134	42	30
Isoleucine	360	390	506	963	318	470	433	141	21	365	38	90
Leucine	450	490	709	350	463	880	538	155	395	694	99	190
Tyrosine	50	60	0	192	157	25	196	108	50	143	10	
Phenylalanine	310	420	267	1039	173	424	394	124	166	229	58	90
Tryptophan	90	90	0	0	0	0	127	0	41	0	0	
Lysine	890	1360	1143	595	556	734	1157	136	137	381	95	50
Histidine	320	460	670	44	190	421	532	139	66	292	3	20
Arginine	0	80	31	349	15	218	338	27	21	381	2	50
γ-Aminobutyric acid								1		69	23	
Taurine								56		190	62	
Essential A.A	3700 (52.2)	5010 (49.7)	4823 (59.3)	3887 (57.0)	2523 (55.9)	4172 (51.9)	4795 (46.9)	1183 (50.0)	1353 (41.0)	2726 (47.4)	465 (32.2)	
Branched-chain A.A[3]	1400 (19.7)	1710 (17.0)	1865 (22.9)	1789 (26.3)	1154 (25.5)	1867 (23.2)	1716 (16.8)	453 (19.1)	673 (20.4)	1436 (25.0)	213 (14.8)	
Umami taste A.A.[4]	1710 (24.1)	2520 (25.0)	1548 (19.0)	1089 (16.0)	982 (21.7)	2024 (25.2)	2442 (23.9)	446 (18.8)	1193 (36.2)	1094 (19.0)	257 (17.8)	
Sweet taste A.A.[5]	2750 (38.8)	4140 (41.2)	3058 (37.6)	1676 (24.6)	1529 (33.8)	2521 (31.4)	3794 (37.1)	706 (29.8)	976 (29.6)	1758 (30.6)	388 (26.9)	
Bitter taste A.A.[6]	2260 (31.9)	2860 (28.4)	3198 (39.3)	3232 (47.4)	1737 (38.5)	2982 (37.1)	2903 (28.4)	830 (35.1)	1013 (30.7)	2091 (36.3)	408 (28.3)	
Total A.A	7090	10,080	8140	6815	4517	8040	10,223	2368	3299	5753	1443	
Reference	[30]	[30]	[30]	[30]	[30]	[31]	[30]	[32]	[33]	[34]	[35]	[46]

[1] All data were rounded to decimal places

[2] The numbers in parentheses are the % values of the total amino acids

[3] Branched-chain A.A: Leucine + isoleucine + valine

[4] Umami taste A.A.: Aspartic acid + glutamic acid

[5] Sweet taste A.A.: Threonine + serine + glycine + alanine + lysine

[6] Bitter taste A.A.: Valine + methionine + isoleucine + leucine + phenylalanine + histidine

(concentration of each amino acid/threshold of each amino acid), the taste-active compounds in all fish sauces are naturally considered aspartic acid and glutamic acid [46]. Glutamic acid is found to increase umami perception and improve overall food preference and is known to have synergistic effects with 5'-nucleotides such as adenylate, inosinate, and guanylate [30].

Fatty acid compositions

The fatty acid contents of salt-fermented fish products are shown in Table 3. In the fatty acid composition of salt-fermented fish, excluding *suan yu* and *shidal* using freshwater fish as raw materials, the proportion of polyunsaturated fatty acids (PUFAs) was the highest, followed by saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFA) [32, 34, 47–51]. On the other hand, the proportion of MUFAs was the lowest in *suan yu* and *shidal* [52, 53]. The ratios of C16:0 and C18:0 were naturally dominant in SFAs, and C16:1 and C18:1 were also dominant in MUFAs.

Among PUFAs, the n-3 series, C22:6, and C20:5, were dominant, and C18:4 was also present in large amounts in fermented fish such as *narezushi*, *tareeh*, and *mehiawh* [34, 51]. The n-6 PUFAs were present in concentrations in the order of C18:2, C18:3, C22:4, and C20:4. These PUFAs are easily oxidized during storage to create off-flavors and odors. However, the added salt suppresses the deterioration of salt-fermented fish's quality and maintains the polyunsaturated fatty acids' content [54, 55].

The proportion of n-6 fatty acids accounted for 3.3–8.9% of salt-fermented fish processed in Asia, such as sardine sauce, *bagoong*, *narezushi*, and *jeotgal*, but n-3 fatty acids accounted for 27.9–34.3%, and 4.6–8.5 times higher than n-6 fatty acids [32, 34, 47–50]. However, in fermented fish such as *tareeh* and *mehiawh* processed in the Arabian Gulf, and *suan yu* and *shidal*, which are made from freshwater fish, n-6 fatty acids were 1.9–3.2 times and 1.2–1.4 times higher than n-3 fatty acids, respectively [51–53].

As a result of calculating the ratio (n-6/n-3) of n-6 fatty acids to n-3 fatty acids in salt-fermented fish, it varied from 0.1 to 3.16. In particular, fermented fish made from freshwater fish such as carp and puntius had the highest values of 3.16 and 1.94, respectively, while fermented fish made from anchovies, shrimp, sandfish, and silver stripe round herring had very low values ranging from 0.1 to 0.29. These low values showed that n-3 series fatty acids were dominant in fermented saltwater fish.

Before industrialization, the ratio of n-6/n-3 series fatty acids in human diets was approximately 1:1–2:1 due to sufficient consumption of vegetables and marine products rich in n-3 fatty acids. However, this ratio gradually increased to approximately 10:1–20:1 due to industrialization [56, 57]. Additionally, overnutrition and Western-style eating habits can further exacerbate this imbalance in the n-6/n-3 ratio. In particular, deficiency of n-3 long-chain PUFA (n-3 LCPUFA), such as eicosapentaenoic acid (EPA) or docosahexaenoic acid (DHA), easily leads to a pro-inflammatory state and increases hyperinsulinemia and insulin resistance [56]. These changes may ultimately lead to the development of nonalcoholic fatty liver disease (NAFLD) and steatosis (hepatocyte triacylglycerol accumulation and cirrhosis) [58].

On the other hand, the consumption of n-3 and n-6 PUFAs is known to have various beneficial effects ranging from fetal development to cancer prevention [59]. Additionally, PUFAs not only have a preventive effect against arterial hypertension, asthma, and inflammatory diseases but also have a preventive effect against breast cancer and immune system disorders [60]. For example, n-3 fatty acids protect against several cardiovascular diseases, such as myocardial infarction, atherosclerosis, arrhythmia, hypertension, and human coronary artery disease [59, 61], lowering blood pressure by reducing platelet aggregation and adhesion to the blood [62]. DHA, an n-3 LCPUFA, plays an important role in developing the nervous system of fetuses and newborns [63]. Therefore, salt-fermented fish products are considered an excellent food material as a source of n-3 fatty acids and nutritional value.

Health benefits of salt-fermented fish

Antioxidant activity

As a consequence of fermentation, the breakdown of fish proteins by endogenous or microbial proteases may release amino acids and peptides with biological activities potentially used as nutraceuticals and functional ingredients for health promotion and disease risk reduction, depending on their structural, compositional, and sequential properties [8, 64].

In studies on the health benefits of salt-fermented fish, antioxidant activity was most frequently reported, followed by angiotensin-I-converting enzyme (ACE) inhibitory activity known as an antihypertensive effect [65–68]. The results are shown in Table 4.

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity method was most commonly used to measure antioxidant activity. This method uses the principle that when DPPH reacts with a proton-donating substance such as an antioxidant, the radical is scavenged, and the absorbance is reduced [69].

The DPPH scavenging activity of salt-fermented fish products varied from 7.05 to 74.14 μmol TE/g sample, with *budu* II (fish sauce made from marine fish) [64] being the highest at 74.14, while *koong-som* (made from small shrimp) [65] and *jaloo* (made from krill) [65] were

Table 3 Fatty acid contents of salt-fermented fish products

Fatty acids (%)	Fish sauce (Sardine)[1]	*Bagoong* I (Shrimp paste)	*Bagoong* II (Shrimp paste)	*Narezushi*[2] (Sandfish)	*Jeotgal* I (Anchovy)	*Jeotgal* II (Silver-stripe round herring)	*Jeotgal* III (Ascidian)	*Suan yu*[3] (Carp)	*Shidal* (Puntius)	*Tareeh* (Sardine paste)	(Area %) *Mehiawh* (Sardine sauce)
C14:0	3.38 ± 0.02	3.5 ± 0.1	3.0	28.7 ± 0.0	9.4	6.6	8.7	1.79 ± 0.02	1.38		
C15:0	0.99 ± 0.19	0.8 ± 0.1			0.6	1.3	1.7	0.36 ± 0.01			
C16:0	24.77 ± 0.02	18.4 ± 1.9	19.8	169 ± 0.2	18.8	24.2	18	18.8 ± 0.20	25.83	6.20 ± 1.20	6.52 ± 0.24
C17:0	1.10 ± 0.01				0.7	-	0.6	0.35 ± 0.00			
C18:0	6.61 ± 0.07	5.4 ± 0.8	7.7	20.6 ± 0.1	4.2	7.1	4	4.12 ± 0.14	10.81	25.84 ± 3.89	24.35 ± 2.80
C20:0	1.06 ± 0.04	0.7 ± 0.1			1	0.9	0.3	0.15 ± 0.00			
C21:0	0.62 ± 0.67										
C22:0	0.19 ± 0.00	1.6 ± 0.2	0.7				0.1	0.04 ± 0.00			
C23:0	0.15 ± 0.00										
C24:0	0.53 ± 0.00	0.4 ± 0.1									
C14:1	0.25 ± 0.19										
C16:1	2.85 ± 0.01	10.0 ± 0.6	6.5	87.7 ± 0.1	12.7	5.7	3.7	5.33 ± 0.00	4.59	1.68 ± 0.14	1.20 ± 0.05
C17:1	0.79 ± 0.02										
C18:1n-9	6.07 ± 0.06	7.2 ± 0.3	7.7	230 ± 2.3	11.4	7.6	5.3	35.9 ± 0.10	25.33	2.59 ± 0.67	2.33 ± 0.57
C18:1n-7		2.6 ± 0.1	2.1	61.9 ± 0.3			7.3		0.45		
C20:1n-9	1.21 ± 0.03		0.9	13.9 ± 0.4	0.1	0.6	0.4	2.09 ± 0.03	0.73		
C22:1n-9	1.15 ± 0.03				0.7	1.3		0.73 ± 0.01	0.14		
C24:1n-9	2.85 ± 0.10	0.5 ± 0.1	0.6							5.59 ± 0.11	7.21 ± 0.87
C16:2n-4		1.2 ± 0.2			1.8	1.9	0.4				
C18:2n-6	8.80 ± 0.12	2.0 ± 0.1	1.4	11.9 ± 0.0	1.2	1.7	4.5	19.2 ± 0.30	10.77	13.94 ± 0.94	12.40 ± 0.73
C16:3n-4		0.6 ± 0.0					0.2				
C18:3n-6	0.08 ± 0.12				0.4	0.8	0.2	0.14 ± 0.00		9.61 ± 0.93	9.66 ± 0.39
C18:3n-3	0.75 ± 0.03	1.6 ± 0.0	1.8		0.7	0.9	1.5		4.18	3.64 ± 0.54	3.03 ± 0.19
C18:4n-3		0.8 ± 0.1		13.6 ± 0.2			2.5		0.23	9.86 ± 1.50	10.24 ± 0.56
C20:2	0.48 ± 0.07				0.1	0.2	0.2	0.44 ± 0.02			
C20:3n-3	0.07 ± 0.10						0.1	0.25 ± 0.01			
C20:4n-6		5.4 ± 0.2	4.8	16.4 ± 0.0	1.7	2.0	1.2	0.90 ± 0.02	0.71	2.98 ± 0.05	1.78 ± 0.19
C20:5n-3	5.86 ± 0.09	13.7 ± 0.6	11	118 ± 0.6	16.3	5.4	16.2	1.40 ± 0.02	0.41	3.34 ± 0.15	3.38 ± 0.13
C22:4n-6										4.58 ± 1.41	5.66 ± 0.34
C22:4n-3		0.9 ± 0.0	1.2								
C22:5n-3		0.6 ± 0.0	1.6	8.6 ± 0.0	1.6	1.4	0.6	0.61 ± 0.00	0.52	1.69 ± 0.84	2.21 ± 0.24
C22:6n-3	24.34 ± 2.23	16.7 ± 0.7	17.1	139 ± 0.3	9.3	24.6	17	4.15 ± 0.04	0.57	4.35 ± 0.87	5.23 ± 0.49
ΣSFA[4]	39.40	30.8	31.2	218.3	34.7	40.1	33.4	25.61	38.02	32.04	30.87

Table 3 (continued)

Fatty acids (%)	Fish sauce (Sardine)[1]	*Bagoong* I (Shrimp paste)	*Bagoong* II (Shrimp paste)	*Narezushi*[2] (Sandfish)	*Jeotgal* I (Anchovy)	*Jeotgal* II (Silver-stripe round herring)	*Jeotgal* III (Ascidian)	*Suan yu*[3] (Carp)	*Shidal* (Puntius)	*Tareeh* (Sardine paste)	(Area %) *Mehiawh* (Sardine sauce)
ΣMUFA[4]	15.17	20.3	17.8	393.5	24.9	15.2	16.7	44.05	31.24	9.86	10.74
ΣPUFA[4]	40.38	43.5	38.9	307.5	33.1	38.9	44.6	27.09	17.39	53.99	53.59
Σn-6	8.88	7.4	6.2	28.3	3.3	4.5	5.9	20.24	11.48	31.11	29.50
Σn-3	31.02	34.3	32.7	279.2	27.9	32.3	37.9	6.41	5.91	22.88	24.09
n-6/n-3	0.29	0.2	0.2	0.1	0.1	0.1	0.2	3.16	1.94	1.36	1.22
Reference	[47]	[48]	[49]	[34]	[32]	[32]	[50]	[52]	[53]	[51]	[51]

[1] The fish in parenthesis is a species used to make fermented fish

[2] Unit was expressed as g/kg of lipid

[3] Unit was expressed as g/100 g of fatty acids

[4] SFA: saturated fatty acid, MUFA: monounsaturated fatty acid, MUFA: polyunsaturated fatty acid

Table 4 Antioxidant activity and ACE inhibitory activity of salt-fermented fish products

Product (Raw fish)	DPPH radical-scavenging activity		ABTS radical-scavenging activity		Ferric reducing antioxidant power (FRAP)[2]	Ferric reducing antioxidant power (FRAP)[3]	Hydrogen peroxide scavenging activity	ACE inhibitory activity		References
	(%)	IC_{50} (mg/ml)	(μmol TE/g protein)[1]	IC_{50} (mg/ml)			(%)	(%)	IC_{50} (mg/ml)	
Budu I (Anchovy)		1.062 ± 0.028		2.146 ± 0.430		0.251 ± 0.007				[74]
Budu II (Marine fish)	74.14 ± 7.54[1]		183.49 ± 1.70		60.86 ± 0.55			65.83 ± 2.69		[64]
Patis I (Anchovy)	69.2 ± 2.8[4]						6.88 ± 0.37[4]			[67]
Patis II (Round scad)	83.5 ± 4.7[4]						9.45 ± 0.69[4]			[67]
Bakasang (Skipjack tuna)								68.8		[77]
Fish sauce (Anchovy)	50.5 ± 1.22									[66]
Jeotgal (*Whang-seoke*)	63.83 ± 0.04					0.15 ± 0.00				[71]
Bagoong (Shrimp)	61.5 ± 0.9[5]						51.1 ± 3.6[5]			[48]
Kapi I (Shrimp)	10.6 ± 0.54[1]		180 ± 0.69		31.9 ± 0.82					[65]
Kapi II (Shrimp)	53.67 ± 0.53[1]		94.40 ± 0.00		42.01 ± 0.34			3.36 ± 0.79		[64]
Kapi III (Shrimp)	49.49 ± 1.19[1]		75.30 ± 2.17		42.23 ± 0.15			42.25 ± 1.92		[64]
Koong-som (Shrimp)	8.58 ± 0.12[1]		67.9 ± 0.15		24.8 ± 0.48					[65]
Kung-chom I (Shrimp)	37.61 ± 0.69[1]		264.17 ± 3.72		31.02 ± 0.19			53.82 ± 4.70		[64]
Kung-chom II (Shrimp)	36.55 ± 0.66[1]		186.40 ± 8.13		27.53 ± 0.09			52.40 ± 0.08		[64]
Jaloo (Krill)	7.05 ± 0.03[1]		152 ± 0.08		24.9 ± 1.28					[65]
Tai-pla (Viscera of fish)	31.57 ± 2.50[1]		86.14 ± 0.63		22.81 ± 0.52			68.17 ± 0.43		[64]
Pla-ra (Freshwater fish)	23.44 ± 3.46[1]		51.79 ± 3.54		8.43 ± 0.02			76.66 ± 1.13		[64]
Pla-som (Freshwater fish)	20.76 ± 0.56[1]		57.14 ± 6.70		10.32 ± 0.43			77.31 ± 1.40		[64]
Pekasam (Freshwater fish)	68.81 ± 0.76	1.36 ± 0.66		2.24 ± 0.58		0.351 ± 0.008				[70]
Ngari (Puntius)	71.32 ± 1.19					0.94 ± 0.01		33.62 ± 1.76		[68]
Sikhae I (Flat-fish)	2.65 ± 0.11	18.87								[26]

Table 4 Antioxidant activity and ACE inhibitory activity of salt-fermented fish products

Product (Raw fish)	DPPH radical-scavenging activity		ABTS radical-scavenging activity		Ferric reducing antioxidant power (FRAP)[2]	Ferric reducing antioxidant power (FRAP)[3]	Hydrogen peroxide scavenging activity	ACE inhibitory activity		References
	(%)	IC_{50} (mg/ml)	(μmol TE/g protein)[1]	IC_{50} (mg/ml)			(%)	(%)	IC_{50} (mg/ml)	
Sikhae II (Alaska pollack)	4.33 ± 0.38	11.55						29.38 ± 5.18	1.70	[73]
Sikhae III (Sea squirt)	67.5							24.8		[72]
Sikhae IV (Squid)		2.68[6]					15.17[6]			[75]

[1] Unit was expressed as μmol TE/g protein, and TE is Trolox equivalent

[2] The unit of FRAP was expressed as μmol TE/g protein, and TE is the Trolox equivalent

[3] Ferric reducing antioxidant power (FRAP) was measured at 700 nm with protein concentration (1 mg/ml)

[4] The samples were 15 and 3 mg for DPPH and H2O2 scavenging activity, respectively

[5] The samples used were 9 mg and 5 mg for DPPH and H2O2 scavenging activity, respectively

[6] Ethanol extract of the sample

the lowest at 8.58 and 7.05, respectively. *Kapi* (made from shrimp) [64, 65] showed 49.49–53.67 μmol TE/g sample and 10.6% depending on the analysis method, regardless of type. *Kung-chom* (made from shrimp) [65] also had a 36.55–37.61 μmol TE/g sample.

When DPPH was analyzed by scavenging activity (%), all salt-fermented fish products except *sikhae* products showed activity above 50%. In particular, *patis* II (round scad sauce) [67] showed the highest scavenging activity at 83.5%, followed by *ngari* (salt-free fermented fish made from puntius) [68] at 71.31%, *patis* I (anchovy sauce) [67] at 69.2%, *pekasam* (made from freshwater fish) [70] at 68.81%, *jeotgal* (made from *whangseoke*) [71] at 63.83%, and *bagoong* (made from shrimp) [48] at 61.5% [48, 66–68, 70, 71]. In addition, *sikhae* III, made from sea squirt, showed a high scavenging activity of 67.5% [72], but *sikhae* I and II, made from flat-fish [26] and Alaska pollack [73], showed the lowest scavenging activity of 2.65 and 4.33%, respectively. Fish sauces such as *patis* [67] and *budu* [67], which had a long fermentation period, generally had higher antioxidant activity than fish pastes such as *kapi* [65] and *jaloo* [65] or salted fish fermented by adding carbohydrates such as *pla-som* [64], *pla-ra* [64], and *koong-som* [65].

The observed changes in antioxidant activities in fish sauces are influenced by the fermentative products, mainly peptides and amino acids, produced due to the prolonged fermentation process [67]. It contains high levels of glutamic acid, alanine, lysine, leucine, and aspartic acid, known for their antioxidative properties [13, 47, 67].

As a result of measuring the IC_{50} (half maximal inhibitory concentration) of DPPH of the salt-fermented fish extract, it was very active at 1.062 mg/ml in *budu* I [74] and 1.36 mg/ml in *pekasam* [70]. However, it was very low at 18.87 mg/ml in flat-fish *sikhae* [26] and 11.55 mg/ml in Alaska pollack *sikhae* [73], respectively, showing a similar tendency to the free amino acid content of salt-fermented fish (Table 2). Meanwhile, the DPPH scavenging activity (IC_{50}) of the alcohol extract of squid *sikhae* was 1.66–2.68 ml/ml, which was higher than that of the water extract (6.09–12.19) and increased with the fermentation period [75]. In a study by Kwon et al. [76], the ingredients such as garlic and red pepper used for kimchi were reported to have antioxidative effects.

The ABTS radical-scavenging activity of salt-fermented fish such as *budu* II, *kapi* II and III, *koong-chom*, *tai-pla*, *pla-ra*, and *pla-som* generally showed a similar trend to the antioxidant results shown in DPPH [64, 65]. However, the scavenging activities of ABTS in *kung-som* I and II and *jaloo*, where the activities of DPPH were lower than that of other salt-fermented fish, were relatively very high [64, 65].

Ferric reducing antioxidant power (FRAP) was the highest in *budu* II at 60.86 μmol TE/g, and the rest of the salted fish generally varied in the range of 8.43–42.01 μmol TE/g [64, 65]. Faithong et al. [65] studied the correlations between antioxidative activities determined by different assays. They reported that the relationship between ABTS and DPPH radical-scavenging activities is correlated very well ($r^2 \geqq 0.9085$) and between ABTS radical-scavenging activities and FRAP ($r^2 \geqq 0.943$). FRAP also correlated with DPPH radical-scavenging activities ($r^2 \geqq 0.9635$) in salt-fermented fish products.

Another method of measuring the antioxidant's capability was hydrogen peroxide scavenging activity, which was 6.88% in patis I (anchovy sauce) [67], 9.45% in patis II (round scad sauce) [70], 51.1% in bagoong (shrimp paste) [48], and 15.17% in the ethanol extract of *sikhae* IV (squid) [75], respectively.

Najafian and Babji [74] separated two novel peptides with strong antioxidant power using HPLC and ESI-TOF MS/MS in *budu*, Lue-Asp-Pro-Val-Phe-Ile-His (LDDPVFIH) and Val-Ala-Gly-Arg-Thr-Asp-Gly-Val-His (VAAGRTDAGVH). Among these peptides, hydrophobic amino acids (Ile and Leu), acidic (Asp), and basic (His) amino acids contribute to the high antioxidant power of *budu*.

In addition, two novel peptides, Ala-Ile-Pro-His-Tyr-Pro (AIPPHYP) and Ile-Ala-Glu-Val-Phe-Leu-Ile-Tre-Asp-Pro (IAEVFLITDPK) with an IC50 of 0.636 mg/ml of ABTS, were isolated and identified from *pekasam* in the same way [70].

Antihypertensive activity

In general, hypertension is associated with angiotensin-I-converting enzyme (ACE), and many peptides showing ACE inhibitory activity are produced through protein degradation during the aging process of salted fish [68, 77–79].

ACE inhibitory activities of extract of salt-fermented fish products varied in the range of 3.36–77.31%, shown in Table 4. Salt-fermented fish, such as *pla-som* and *pla-ra*, made with freshwater fish, salt, and carbohydrates, showed the highest activity at 77.31% and 76.66%, respectively [64]. Next, *bakasang*, made from skipjack tuna, is a typical fish sauce in Indonesia, at 68.8% [80], followed by *tai-pla*, made from fish viscera, at 68.17% [64]. In *kung-chom* I and II, made with shrimp, salt, and roasted rice, the activity was 53.82 and 52.40%, respectively [64], whereas in *kapi* II and III, shrimp paste using shrimp and salt only, the change in activity was very large at 3.36% and 42.25%, respectively [64]. Compared with the other products, *douchi*, a traditional Chinese fermented soybean, contained 56.8% to 76.3% ACE inhibitory activity [80].

Less ACE inhibitory was exhibited by *ngari* of India at 33.62% activity [71], and *sikhae* II and III made from Alaska pollack and sea squirt showed 29.38% and 24.8% activity, respectively [72, 73]. These different activities are considered to be due to the raw materials, ingredients, and processing employed according to local producers [64]. Phadke et al. [68] reported that higher ACE inhibition was observed significantly at higher protein concentrations by all the *ngari* samples fermented for different periods ($P < 0.05$), and ACE inhibitory activity increased with fermentation time.

On the other hand, in blue mussel [81] and oyster sauce [82], which are fish sauces using shellfish, IC_{50} values of ACE inhibitory activity appeared to be 1.01 mg/ml and 2.45 mg/ml, respectively, showing similar activity to IC_{50} 1.70 ml/ml in Alaska pollack *sikhae* [73]. Je et al. [81, 82] also isolated and purified peptides showing competitive inhibition of ACE from blue mussel- and oyster-fermented sauces, and their IC_{50} values of ACE inhibition were 2.98 μM (blue mussel sauce, MW 6.5 kDa) and 0.147 mM (oyster sauce, MW 593 Da), and reported that they effectively reduced blood pressure in spontaneous hypertension rats (SHR) after oral administration. As a result of oral administration of *narezushi* water extract having ACE inhibitory activity (IC_{50} value 0.06 mg/mL), the systolic blood pressure of SHR was effectively reduced [83].

Many studies have reported the direct isolation of peptides with strong ACE-inhibiting ability from these fermented fish products. Okamoto et al. [84] isolated three peptides from the fermented salmon sauce, Gly-Trp, Ile-Trp, and Val-Trp. In a similar study, Ichimura et al. [85] isolated nine peptides having ACE inhibitory activity, such as Ala-Pro, Lys-Pro, Arg-Pro, Gly-Pro, Glu-Pro, Thr-Pro, Val-Pro, Gly-Ile, and Asp-Phe from anchovy sauce and also nine peptides from sardine sauce, and four peptides from bonito sauce, respectively. The reason why so many peptides containing proline with high ACE inhibitory activity are isolated from fish sauces is thought to be because of the unique structure of proline being an imine acid [85]. Peptide bonds containing proline residues, therefore, are resistant to hydrolysis by general peptidases. This may be the reason why these proline-containing dipeptides survived long-term fermentation [8, 85]. specially, three peptides, Arg–Pro, Lys–Pro, and Ala–Pro, from three sauces (anchovy, sardine, and bonito) showed the highest ACE inhibitory activity, with IC_{50s} of 21, 22, and 29 μM, respectively. Ichimura et al. [85] reported that the oral administration of Lys–Pro reduced the blood pressure of SHRs [85], and fermented anchovy sauce itself also stimulated insulin secretion by cultured RINm5F insulinoma cells.

Although fermented fish products may not be directly used as a functional food because of their high concentration of sodium chloride, the sauce may be useful as a source of biologically active substances. Since the high salt content of salt-fermented fish, however, is known to be a causative agent of adult diseases such as high blood pressure, it is considered that epidemiological studies related to the intake of these salt-fermented fish should also be added.

Other biological activities

Fibrinolytic enzymes, known as thrombolytic agents, were found in various fermented foods. High fibrinolytic activity has been reported in traditional fermented fish of India, such as *ngari* and *shedal* [86] as well as in fermented shrimp, anchovy, and yellow corvine Korean *jeotgal* products [87]. Cha et al. [26] also reported that flat-fish and Alaska pollack *sikhaes* showed strong fibrinolytic enzyme activity comparable to that of *kimchi*, and that this was due to the effect of organic acids produced by lactic acid fermentation [88].

Some lactic acid bacteria (LAB), such as *Lactobacillus* sp. (*L. plantarum, L. pentosus*, *L. sakei*) isolated from fermented fish products, have demonstrated healthy effects [89, 90]. These LABs are known to produce bacteriocin, which inhibits pathogens [1]. When consumed in foods, the metabolites of this group of bacteria are known to have probiotic effects [1]. Therefore, these LAB strains can be used to design probiotic formulations or to produce new fermented seafood products [91].

Functional activities in the ethanol extract of squid *sikhae*, such as inhibitions on α-glucosidase, β-glucuronidase, and elastase, were found [75], while bile acid binding capacity (23.80 mM/g) [92] and XO inhibitory activity (IC_{50} value: 0.56 mg/ml) [73] were observed in Alaska pollack *sikhae* during fermentation. Additionally, fermented low-salt squid (*Todarodes pacificus*) *jeotgal* improved the learning and memory impairments in SD rats by inhibiting acetylcholinesterase activity in the brain [93]. In another study, the hydrophobic peptide fraction isolated from anchovy fish sauce has been shown to have a strong anti-proliferative effect against human lymphoma cells (U937) by inducing this apoptosis (IC_{50} value: 31 μg/mL) [8]. Coenzyme Q, known as an energy booster and immune-system enhancer, is also found in a large amount of 291.0 mg/g in *jeotgal*, Korean fermented fish [94]. However, the efficacy of these in vitro results is considered necessary for further future verification studies through animal and human tests.

On the other hand, a specific study on the daily intake of salt-fermented fish has yet to be introduced. Therefore, additional research on the functional promotion effect related to the consumption of salt-fermented fish

Table 5 Biogenic amine contents and their reduction effects in salt-fermented fish products[1]

Sample	TRY	PHE	PUT	CAD	HIS	SER	TYR	SPD	NOR	DOP	SPM	(mg/kg) References
Anchovy sauce	35.0–193.5	20.0–36.9	41.8–173.3	100.0–253.0	196.0–393.2	ND[2]-7.9	211.4–446.0	0.8–6.7	ND[2]	5.5–23.8	1.4–4.1	[97]
Sand lance sauce	122.5–242.5	18.3–32.5	30.8–43.8	52.5–168.3	183.4–1038.9	9.2–41.5	155.7–252.4	3.4–6.4	ND-5.4	11.8–46.9	1.2–5.6	[97]
Jeotgal I (Shrimp)[3]	3.3–8.1	ND-4.2	2.8–5.4	ND-1.5	2.3- 12.7	4.7- 18.3	1.4–7.4	ND-0.8	ND-12.1	44.3–184.8	0.4–9.6	[97]
Jeotgal II (Squid)	ND-5.4	ND	0.6- 17.3	ND-64.7	1.0–27.5	2.2–4.0	ND-18.6	ND-0.9	ND-2.7	ND-25.8	0.8–25.7	[97]
Jeotgal III (Viscera)	ND-7.0	ND-3.1	14.3–44.5	3.2–396.0	2.6–21.0	2.5–10.2	1.3–65.9	2.6–3.6	ND-6.1	3.6–28.3	2.7–29.6	[97]
Jeotgal IV (pollack roe)	ND	ND	ND-23.3	ND-2.9	ND-4.6	ND-8.4	ND-0.9	0.9–2.6	ND	ND-39.9	ND-47.4	[97]
Jeotgal V (Clam)	ND-2.9	ND-1.6	2.6–8.9	1.9–444.0	ND-3.3	1.5–7.8	ND-10.2	ND-4.7	ND-5.9	0.6–31.6	10.0–78.7	[97]
Jeotgal VI (Yellow corvina)	ND-4.1	ND-2.2	1.2–3.6	1.2–34.2	55.2–88.9	12.2–18.2	5.2–13.4	1.2–3.7	1.2–9.6	15.2–160.8	ND-2.2	[97]
Narezushi (Sandfish)[4]	70 ± 0.0		370 ± 50	40 ± 0.0	10 ± 0.0	50 ± 0.0	340 ± 30					[98]
Anchovy fish sauce I[5] (before fermentation)	1.57 ± 0.23	0.85 ± 0.13	3.61 ± 0.16	20.64 ± 0.29	7.24 ± 0.21		11.24 ± 0.17					[66]
Anchovy fish sauce II[5] (after fermentation)	0.71 ± 0.16	ND	3.43 ± 0.15	23.50 ± 0.30	5.20 ± 0.20		7.76 ± 0.20					[66]
Pekasam I (Carp) (Naturally fermentation)	14.1 ± 10.3	20.4 ± 6.5	133.5 ± 75.2	136.7 ± 63.1	66.8 ± 37.5		39.3 ± 24.1	3.5 ± 1.2			4.2 ± 1.5	[23]
Pekasam II (Carp)[6] (Acid-assisted fermentation)	12.7 ± 11.5	21.4 ± 14.1	115.2 ± 54.5	105.5 ± 74.4	51.7 ± 40.4		65.5 ± 42.0	3.6 ± 2.0			5.8 ± 2.4	[23]
Layú I (Carp) (fermented without sucrose)			22.1 ± 0.95	77.1 ± 1.9	25.6 ± 0.67		15.3 ± 0.68	2.1 ± 0.08			1.5 ± 0.09	[102]
Layú II (Carp) (fermented with sucrose)			16.4 ± 0.71	55.7 ± 1.5	21.4 ± 1.4		15.2 ± 0.77	2.1 ± 0.17			1.8 ± 0.18	[102]

[1] TRY, tryptamine; PHE, 2-phenylethylamine; PUT, putrescine; CAD, cadaverine; HIS, histamine; SER, serotonin; TYR, tyramine SPD, spermidine; NOR, noradrenaline; DOP, dopamine; SPM, spermine

[2] ND: not detected

[3] Fish, in the parenthesis, is a raw material

[4] The original data (g/kg) was converted to mg/kg

[5] Biogenic amine contents (mg/L) were expressed in anchovy fish sauce before and after fermentation with *Aspergillus oryzae*

[6] Acid-assisted fermentation was processed with tamarind (*Tamarindus indica*) pulp or dried slices of Garcinia atroviridis fruit

is expected to contribute significantly to improving the processing suitability of fermented fish products.

Biogenic amines and their reduction in salt-fermented fish

Intake of low amounts of biogenic amines, produced by decarboxylation of amino acids in foods, does not harm human health [95, 96]. However, when their amount in food is too high, and detoxification ability is inhibited or disturbed, biogenic amines could cause problems such as rashes, migraines, high blood pressure, and low blood pressure after ingestion [8, 96].

A total of 11 types of biogenic amines were analyzed in salt-fermented fish (Table 5). Among them, five types, including tryptamine, putrescine, cadaverine, histamine, and tyramine, were detected as major amines in anchovy and sand lance sauce, and six types, including phenylethylamine, serotonin, spermidine, noradrenaline, dopamine, and spermine, were detected as minor amines (Table 5)[97]. In *jeotgal* I, made from shrimp, except for dopamine, the remaining amines were detected in small amounts, whereas in *jeotgal* II (squid), except for high amounts of cadaverine, the remaining amines were generally low in content [97]. This trend was similar to the rest of the salt-fermented fish, with high levels of cadaverine and tyramine detected in *jeotgal* III (viscera), cadaverine and spermine in *jeotgal* V (clam), and histamine and dopamine in *jeotgal* VI (yellow corvina) [97]. In *narezushi* (sandfish), the content of putrescine was highest at 370 mg/kg, followed by tyramine at 340 mg/kg, tryptamine at 70 mg/kg, and histamine was the least detected at 10 mg/kg [98]. Gowda et al. [17], however, reported that the predominant amines detected in fish sauces are six types: histamine, putrescine, cadaverine, tyramine, tryptamine, and phenylethylamine.

Meanwhile, the U.S. Food and Drug Administration (FDA) has recommended that the concentrations of histamine, tyramine, and total biogenic amines among fish and seafood products be less than 50 mg/kg, 100 mg/kg, and 1000 mg/kg, respectively, and less than 500 mg/kg in fish sauce [99, 100]. The European Union (EU) states that the acceptable histamine level should be less than 400 mg/kg for fish sauce [8]. In Canada, Finland, Switzerland, and South Africa, the total amount of biogenic amines allowed for fish and seafood products is 100 mg/kg [101].

Therefore, many studies have attempted to develop methods to reduce the content of biogenic amines in fermented fish. As shown in Table 5, all of the biogenic amines decreased after fermentation except for cadaverine in anchovy sauce produced by *Aspergillus oryzae* [66]. In addition, when acid-assisted fermentation was performed by adding tamarind pulp or dripped slipper fruit, the average values of putrescine, cadaverine, and histidine were not significant compared to naturally fermented *Ikan pekasam*, but there was a reducing effect in the range of 13.7–22.8%, respectively [23]. Moreover, the total biogenic content in layú II fermented by adding sucrose was 112.5 mg/kg, 21.7% lower than in the case of no addition (143.7 mg/kg) [102].

On the other hand, Mah and Hwang reported that biogenic amine concentration decreased by 16% in fermented anchovy *jeotgal* by inoculating with *Staphylococcus xylosus* 0538 compared to controls. In particular, the resolution was highest for histamine [103]. Supplementation of *Moringa oleifera* leaves (5–10%, w/w) was also reported as the effect of reducing histamine without sensory problems in the quality of fermented shrimp paste [104].

Additional research on reducing biogenic amines is thought to be needed in the future to improve the quality of these salt-fermented fish and stabilize food hygiene.

Conclusion

Salt-fermented fish is a traditional seafood that has been favored in many regions of the world for a long time. Fermented fish products can be divided into three groups depending on the fermentation type. The final product consists of fish (or crushed fish paste) and salt only, fish sauce (used as liquid) after filtrating, and fish lacto-fermented with a source of carbohydrates (cooked rice, vegetables, millet, and malt). These fermented fish are not only nutritionally superior in terms of free amino acid content that is produced through fermentation but also have excellent functionality such as antioxidant and ACE-inhibiting ability and also contain large amounts of omega-3 series substances (EPA and DHA) that were effective in preventing cardiovascular diseases. Some lactic acid bacteria (LAB) isolated from fermented fish products are known to have beneficial effects on humans, including bacteriocin and probiotic effects. However, the efficacy of these in vitro test results is considered necessary for further future verification studies through animal or human tests. Moreover, since the salt content added is high for storage, it is believed that processing methods that reduce sodium chloride and biogenic amines will satisfy the tastes of modern society.

Author contributions

YJ Cha contributed to the conceptualization, writing—original draft, review, and editing of the final draft; D Yu was involved in the data collection, review, and editing of the manuscript.

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References

1. Kumar S, Nayak BB. Health benefits of fermented fish. In: Tamang JP, editor. Health benefits of fermented foods and beverages. Boca Raton, FL: CRC Press; 2015. p. 475–88.
2. Lee CH. A study on the origin of fermentation culture in Northeast Asia. Food Sci Ind. 2020;53(2):134–47.
3. Lee JS, Park JM, Kim AJ. The History of salted-seafood consumption and an evaluation of its nutritional and functional value. Asian J Beauty Cosmetol. 2022;20(2):273–84.
4. Fujii T, Wu YC, Suzuk T, Kimura B. Production of organic acids by bacteria during the fermentation of squid shiokara. Fish Sci. 1999;65:671–2.
5. Steinkrauss KH. Fermentations in world food processing. Compr Rev Food Sci Food Saf. 2002;1:23–32.
6. Zang J, Xu Y, Xia W, Regenstein JM. Quality, functionality, and microbiology of fermented fish: a review. Crit Rev Food Sci Nutr. 2020. https://doi.org/10.1080/10408398.2019.1565491.
7. Kim YM, Kang MC, Hong JH. Quality evaluation of low-salt fermented seafoods. Korean J Fish Aquat Sci. 1995;28:301–8.
8. Martínez-Álvarez O, López-Caballero ME, Gómez-Guillén MC, Montero P. Fermented seafood products and health. In: Frias J, Martinez-Villaluenga PE, editors. Fermented foods in health and disease prevention. Cambridge: Academic Press; 2017. p. 177–202.
9. Kim SM. The present condition and development prospect of the fermented fishery products. Food Sci Ind. 2020;53(2):200–14.
10. Kim HK, Kim GT, Kim DK, Choi WA, Park SH. Purification and characterization of a novel fibrinolytic enzyme from Bacillus sp KA 38 originated from fermented fish. J Ferment Bioeng. 1997;84:307–12.
11. Ishige N, Ruddle K. Gyoshō to narezushi no kenkyū: Monsūn Ajia no shokuji bunka (Japanese edition). Iwanami Shoten, Tokyo, Japan. 1990. ISBN-10. 4000027212.
12. Giri A, Osako K, Okamoto A, Ohshima T. Olfactometric characterization of aroma active compounds in fermented fish paste in comparison with fish sauce, fermented soy paste and sauce products. Food Res Int. 2010;43(4):1027–40.
13. Lopetcharat K, Choi YJ, Park JW, Daeschel MA. Fish sauce products and manufacturing: A review. Food Rev Int. 2001;17(1):65–88.
14. Rabie M, Simon-Sarkadi L, Siliha H, El-Seedy S, El-Badawy AA. Changes in free amino acids and biogenic amines of Egyptian salted-fermented fish (Feseekh) during ripening and storage. Food Chem. 2009;115(2):635–8.
15. Oguntoyinbo FA. Safety challenges associated with traditional foods of West Africa. Food Rev Int. 2014;30(4):338–58.
16. Thapa N, Pal J, Tamang JP. Microbial diversity in Ngari, Hentak and Tungtap, fermented fish products of North-East India. World J Microbiol Biotechnol. 2004;20(6):599–607.
17. Gowda SGS, Narayan B, Gopal S. Bacteriological properties and health-related biochemical components of fermented fish sauce: An overview. Food Rew Int. 2016;32(2):203–29.
18. Curtis RI. Umami and the foods of classical antiquity. Am J Clin Nutr. 2009;90:712s–8s.
19. Ijong FG, Ohta Y. Amino acid compositions of Bakasang, a traditional fermented fish sauce from Indonesia. LWT-Food Sci Technol. 1995;28:236–7.
20. Jiang JJ, Zeng QX, Zhu ZW, Zhang LY. Chemical and sensory changes associated Yu-lu fermentation process – A traditional Chinese fish sauce. Food Chem. 2007;104(4):1629–34.
21. Russo GL, Langellotti AL, Genovese A, Martello A, Sacchi R. Volatile compounds, physicochemical and sensory characteristics of *Colatura di Alici*, a traditional Italian fish sauce. J Sci Food Agric. 2020;100(9):3755–64.
22. Kopermsub P, Yunchalard S. Identification of lactic acid bacteria associated with the production of plaa-som, a traditional fermented fish product of Thailand. Int J Food Microbiol. 2010;138(3):200–4.
23. Ezzat MA, Zare D, Karim R, Ghazali HM. Trans- and cis-urocanic acid, biogenic amine and amino acid contents in ikan pekasam (fermented fish) produced from Javanese carp (Puntius gonionotus) and black tilapia (Oreochromis mossambicus). Food Chem. 2015;172:893–9.
24. Kanno T, Kuda T, An C, Takahashi H, Kimura B. Radical scavenging capacities of Saba-narezushi, Japanese fermented chub mackerel, and its lactic acid bacteria. LWT Food Sci Technol. 2012;47(1):25–30.
25. Kuda T, Mihara T, Yano T. Detection of histamine and histamine-related bacteria in fish-nukazuke, a salted and fermented fish with rice-bran, by simple colorimetric microplate assay. Food Control. 2007;18:677–81.
26. Cha YJ, Cho DH, Seo JH, Cho WJ, Jeong EJ. Comparison of biological activities in *sikhae*, traditional fermented sea products. Korean J Fish Aquat Sci. 2005;38:1–5. https://doi.org/10.5657/kfas.2005.38.1.001.
27. Cha YJ, KIM H, Cho WJ, Jeong EJ. Volatile flavor compounds and nutritional values in Alaska Pollack *sikhae* made by two-stage fermentation. In: Do CH, Rimando AM, Kim YM (eds) Chemistry of Korean foods and beverages. American Chemical Society, Washington, DC. 2019. 25–42.
28. Taira W, Funatsu Y, Satomi M, Jakano T, Abe H. Changes in extractive components and microbial proliferation during fermentation of fish sauce from underutilized fish species and quality of final products. Fish Sci. 2007;73:913–23.
29. Sanceda N, Kurata T, Arakawa N. Accelerated fermentation process for the manufacture of fish sauce using histidine. J Food Sci. 1996;61:220–5.
30. Ninomiya K. Umami: a universal taste. Food Rev Int. 2002;18(1):23–38.
31. Lee MH, Chang YH, Jeong IH. Fermentation characteristics of anchovy *Engraulis japonicus* sauce amended with onion. Korean J Fish Aquat Sci. 2021;54:714–23. https://doi.org/10.5657/KFAS.2021.0714.
32. Kim HJ, Yoon MS, Park YS, Ha JH, Heu MS, Kim JS. Food component characteristics of commercial salt-fermented silver-stripe round herring. J Korean Fish Soc. 2009;42(2):116–22.
33. Kouakou AC, N'Guessan KF, Durand N, Thomas DA, Montet D, Djè MK. Molecular bacterial characterization and free amino acids composition in Ivorian traditional fermented fish produced by two methods. Fish Sci. 2012;78:1125–36.
34. Chang CM, Ohshima T, Koizumi C. Changes in composition of lipids, free amino acids and organic acids in rice-bran-fermented sardine (*Etrurneus teres*) during processing and subsequent storage. J Sci Food Agric. 1992;59:521–8.
35. Cha YJ, Kim SJ, Jeong EJ, Kim H, Cho WJ, Yoo MY. Studies on taste compounds in Alaska pollack sikhae during fermentation. J Korean Soc Food Sci Nutr. 2004;33(9):1515–21.
36. Shimomura Y, Yamamoto Y, Bajotto G, Sato J, Murakami T, Shimomura N, Kobayashi H, Mawatari K. Nutraceutical effects of branched-chain amino acids on skeletal muscle. J Nutr. 2006;136(2):529S-532S.
37. Kuriyama K. Taurine as a neuromodulator. Federation Proc. 1980;39:2680–4.
38. Thurston JH, Hauhart RE, Dirgo JA. Taurine: a role in osmotic regulation of mammalian brain and possible clinical significance. Life Sci. 1980;26:1561–8.
39. Pasantes MH, Wright CE, Gaull GE. Taurine protection of lymphoblastoid cells from iron-ascorbate-induced damage. Biochem Pharm. 1985;34:2205–7.
40. Wright CE, Tallan H, Lin YY. Taurine: biological update. Annu Rev Biochem. 1986;55:427–53.
41. Huxtable RJ. Physiological actions of taurine. Physiol Rev. 1992;72:101–63.

42. Park PJ, Je JY, Kim SK. Amino acid changes in the Korean traditional fermentation process for blue mussel (*Mytilus edulis*). J Food Biochem. 2005;29(1):108–16.
43. Barragan A, Weidner JM, Jin Z, Korpi ER, Birnir B. GABAergic signalling in the immune system. Acta Physiol. 2015;213:819–27.
44. Fuke S, Shimizu T. Sensory and preference of umami. Trends Food Sci Technol. 1993;4:246–51.
45. Kagawa M, Matsumoto M, Hatae K. Taste differences among three kinds of squid and the effect of cold storage on the taste. J Home Econ Japan. 1999;50:1245–54.
46. Kato H, Rhue M, Nishimura T. Role of free amino acids and peptides in food taste. In: Teranishi R, Buttery RG, Shahidi F, editors. Flavor chemistry: Trends and development. Washington DC: American Chemical Society; 1989. p. 158–74.
47. Dincer T, Cakli S, Kilinc B, Tolasa S. Amino acids and fatty acid composition content of fish sauce. J Anim Vet Adv. 2010;9(2):311–5.
48. Peralta EM, Hatate H, Kawabe D, Kuwahara R, Wakamatsu S, Yuki T, Murata H. Improving antioxidant activity and nutritional components of Philippines salt-fermented shrimp paste through prolonged fermentation. Food Chem. 2008;111:72–7.
49. Peralta EM, Hatate H, Watanabe D, Kawabe D, Murata H, Hama Y, Tanaka R. Antioxidative activity of Philippines salt-fermented shrimp and variation of its constituents during fermentation. J Oleo Sci. 2005;54(10):553–8.
50. Kim YA, Kang ST, Kang JG, Kang JY, Yoo UH, Oh KS. Processing and quality characteristics of low-salt fermented ascidian *Halocynthia roretzi*. Korean J Fish Aquat Sci. 2006;39:283–91. https://doi.org/10.5657/kfas.2006.39.3.283.
51. Freije A. Fatty acid compositions of raw fish white sardinella (Oom), fish paste (Tareeh), and fish sauce (Mehiawh): fermented fish products rich in polyunsaturated fatty acids. Bahrain Medcal Bull. 2017;39(4):200–9.
52. Xu Y, Xie Y, Xia W, Regenstein JM, Gao P. Lipid fraction and fatty acid profile changes in low-salt fermented fish as affected by processing stage and inoculation of autochthonous starter cultures. LWT-Food Sci Technol. 2018;97:289–94.
53. Majumdar RK, Basu S, Nayak BB. Assessment of nutritional quality of "Shidal", a fermented fish product of northeast India. J Indian Fish Assoc. 2009;36:25–34.
54. Aubourg SP. Lipid damage detection during the frozen storage of an underutilized fish species. Food Res Int. 1999;32(7):497–502.
55. El-Sebaiy LA, Metwalli SM. Changes in some chemical characteristics and lipid composition of salted fermented bouri fish muscle (*Mugil cephalus*). Food Chem. 1988;31(1):41–50.
56. Freije A, Alkaabi AM. Fatty acid compositions in fermented fish products. In: Baez RV (ed) Advances in lipid metabolism. IntechOpen, http://doi/https://doi.org/10.5772/intechopen.73796 2020, 73–86
57. Bulla MK, Simionato JI, Matsushita M, CorÓ FAG, Shimokomaki M, Visentainer JV, et al. Proximate composition and fatty acid profile of raw and roasted salt-dried sardines (*Sardinella Brasiliensis*). Food Nutr Sci. 2011;2:440–3.
58. Valenzuela R, Videla LA. The importance of the long-chain polyunsaturated fatty acid n-6/n-3 ratio in development of non-alcoholic fatty liver associated with obseity. Food Funct. 2011;2:644–8.
59. Louly AWOA, Gaydou EM, ElKebir MVO. Muscle lipids and fatty acids profiles of three edible fish from the Mauritanian coast: *Epinephelus aeneus*, *Cephalopholis taeniops* and *Serranus scriba*. Food Chem. 2011;124:24–8.
60. Njinkoué JM, Barnathan G, Miralles J, Gaydou EM, Samb A. Lipids and fatty acids in muscle, liver and skin of three edible fish from the Senegalese coast: *Sardinella maderensis*, *Sardinella aurita*, and *Cephalopholis taeniops*. Comp Biochem Physiol Part B. 2002;131:395–402.
61. Hirafuji M, Machida T, Hamaue N, Minami M. Cardiovascular protective effects of n-3 polyunsaturated fatty acids with special emphasis on docosahexaenoic acid. J Pharmacol Sci. 2003;92(4):308–16.
62. Dyerberg J, Bang HO. Haemostatic function and platelet polyunsaturated fatty acids in Eskimos. Lancet. 1979;2(8140):433–5.
63. Echeverria F, Valenzuela R, Hernandez-Rodas MA. Docosahexaenoic acid (DHA), a fundamental fatty acid for the brain: Newdietry sources. Prostaglandins Leukot Essent Fatty Acids. 2017;124:1–10.
64. Lertprakobkit W. Study on angiotensin-I-converting enzyme inhibitory activity and antioxidant activity of peptides derived from some Thai traditional fermented fishery products. A master thesis, Prince of Songkla Univ. 2011: p.1–113.
65. Faitthong N, Benjakul S, Phatcharat S, Binsan W. Chemical composition and antioxidative activity of Thai traditional fermented shrimp and krill products. Food Chem. 2010;119:133–40.
66. Sun J, Yu X, Fang B, Ma L, Xue C, Zhang Z, Mao X. Effect of fermentation by Aspergillus oryzae on the biochemical and sensory properties of anchovy (Engraulis japonicus) fish sauce. Int J Food Sci Technol. 2016;51:133–41.
67. Peralta EM. The relationship of antioxidant activity and browning, as index of Maillard reaction products (MRPs), in Philippines fish sauce. Philippines J of Nat Sci. 2010;15:75–80.
68. Phadke G, Elavarasan K, Shamasundar BA. Angiotensin-I converting enzyme (ACE) inhibitory activity and antioxidant activity of fermented product Ngari as influenced by fermentation period. Int J Pharm Bio Sci. 2014;5:134–42.
69. Shimada K, Fujikawa K, Yahara K, Nakamura T. Antioxidative properties of xanthan on the antioxidation of soy bean oil in cyclodextrin emulsion. J Agric Food Chem. 1992;40:945–8.
70. Najafian L, Babji AS. Fractionation and identification of novel antioxidant peptides from fermented fish (pekasam). J Food Meas Charact. 2018;12:2174–83.
71. Kim JS, Moon GS, Lee KH, Lee YS. Studies on quality changes and antioxidant activity during the fermentation of salt fermented Whangseoke. J Korean Soc Food Sci Nutr. 2006;35(2):171–6.
72. Kim PH, Kim MJ, Kim JH, Lee JS, Kim KH, Kim HJ, Jeon YJ, Heu MS, Kim JS. Nutritional and physiologically active characterizations of the sea squirt Halocynthia roretzi sikhae and the seasoned sea squirt. Korean J Fish Aquat Sci. 2014;47:1–11. https://doi.org/10.5657/KFAS.2014.0001.
73. Cha YJ, Lee CE, Jeong EJ, Kim H, Cho WJ, Nam GJ. Biological activity in traditional Alaska pollack sikhae during low temperature fermentation. BioFactors. 2004;22:319–21.
74. Najafiana L, Babji AS. Purification and identification of antioxidant peptides from fermented fish sauce (Budu). J Aquat Food Prod Technol. 2019;28(1):14–24.
75. Cho WI, Kim SM. The biofunctional activities and shelf-life of low-salt squid sikhae. Korean J Food Sci Technol. 2012;44(1):61–8.
76. Kwon MJ, Song YS, Song YO. Antioxidative effect of kimchi ingredients on rabbits fed cholesterol diet. J Korean Soc Food Sci Nutr. 1998;27:1189–96.
77. Wenno MR, Suprayitno E, Aulanni'am A, Hardoko H. The physicochemical characteristics and angiotensin converting enzyme (ACE) inhibitory activity of skipjack tuna (*Katsuwonus pelamis*) "Bakasang." J Teknologi (Sci Eng). 2016;78:119–24.
78. Itou K, Akahane Y. Antihypertensive effect of Heshiko, a fermented mackerel product, on spontaneously hypertensive rats. Fish Sci. 2004;70(6):1121–9.
79. Itou K, Kobayashi S, Ooizumi T, Akahane Y. Changes of proximate composition and extractive components in Narezushi, a fermented mackerel product, during processing. Fish Sci. 2006;72(6):1269–76.
80. Zhang JH, Tatsumi E, Ding CH, Li LT. Angiotensin I-converting enzyme inhibitory peptides in douchi, a Chinese traditional fermented soybean product. Food Chem. 2006;98(3):551–7.
81. Je JY, Park PJ, Byun HG, Jung WK, Kim SK. Angiotensin I converting enzyme (ACE) inhibitory peptide derived from the sauce of fermented blue mussel. Mytilus edulis Bioresour Technol. 2005;96(14):1624–9.
82. Je JY, Park JY, Jung WK, Park PJ, Kim SK. Isolation of angiotensin I converting enzyme (ACE) inhibitor from fermented oyster sauce Crassostrea gigas. Food Chem. 2005;90(4):809–14.
83. Itou K, Nagahashi R, Saitou M, Akahane Y. Antihypertensive effect of narezushi, a fermented mackerel product, on spontaneously hypertensive rats. Fish Sci. 2007;73(6):1344–52.
84. Okamoto A, Matsumoto E, Iwashita A, Yasuhara T, Kawamura Y, Koizumi Y, Yanagida F. Angiotensin I-converting enzyme inhibitory action of fish sauce. Food Sci Technol Int. 1995;1:101–6. https://doi.org/10.3136/fsti9596t9798.1.101.
85. Ichimura T, Hu J, Aita DQ, Maruyama S. Angiotensin I-converting enzyme inhibitory activity and insulin secretion stimulative activity of fermented fish sauce. J Biosci Bioeng. 2003;96(5):496–9.
86. Singh TA, Devi KR, Ahmed G, Jeyaram K. Microbial and endogenous origin of fibrinolytic activity in traditional fermented foods of Northeast India. Food Res Int. 2014;55:356–62.

87. Hwang KJ, Choi KH, Kim MJ, Park CS, Cha J. Purification and characterization of a new fibrinolytic enzyme of *Bacillus licheniformis* KJ-31, isolated from Korean traditional Jeot-gal. J Microbiol Biotechnol. 2007;17(9):1469–76.
88. Jeong YK, Yang WS, Kang JO, Kong IS, Kim JO. Fibrinolysis of fermented Kimchi. Korean J Life Sci. 1995;5:203–10.
89. Kim KP, Rhee CH, Park HD. Degradation of cholesterol by *Bacillus subtilis* SFF34 isolated from Korean traditional fermented flatfish. Lett Appl Microbiol. 2002;35(6):468–72.
90. Thapa N, Pal J, Tamang JP. Microbial diversity in ngari, hentak, and tungkap, fermented fish products of North-East India. World J Microbiol Biotechnol. 2004;20:599–607.
91. Wong AHK, Mine Y. Novel fibrinolytic enzyme in fermented shrimp paste, a traditional Asian fermented seasoning. J Agric Food Chem. 2004;52(4):980–6.
92. Cha YJ, Lee CE, Jeong EK, Kim H, Lee JS. Physiological functionalities of traditional Alaska pollack sikhae. J Korean Soc Food Sci Nutr. 2002;31(4):559–65.
93. Heo JS, Kim JB, Cho SY, Sohn KH, Choi JW. Low-salt *Todarodes pacificus* jeotgal improves the learning and memory impairments in scopolamine-induced dementia rats. Kor J Fish Aquat Sci. 2014;47(3):195–203.
94. Pyo YH, Oh HJ. Ubiquinone contents in Korean fermented foods and average daily intakes. J Food Compost Anal. 2011;24(8):1123–9.
95. Santos MHS. Biogenic amines: their importance in foods. Int J Food Microbiol. 1996;29:213–31.
96. Doeun D, Davaatseren M, Chung MS. Biogenic amines in foods. Food Sci Biotechnol. 2017;26(6):1463–74.
97. Shin SW, Kim YS, Kim YH, Kim HT, Eum KS, Hong SR, Kang HJ, Park KH, Yoon MH. Biogenic-amine contents of Korean commercial salted fishes and cabbage kimchi. Korean J Fish Aquat Sci. 2019;52:13–8. https://doi.org/10.5657/KFAS.2019.0013.
98. Chang CM, Ohshima T, Koizumi C. Changes in the composition of free amino acid, organic acids and lipids during processing and ripening of 'Hatahata-zushi', a fermented fish product of sandfish (*Arctoscopus japonicus*) and boiled rice. J Sci Food Agric. 1994;66:75–82.
99. FDA. FDA's Evaluation of the Seafood HACCP Program for Fiscal Years 2000/2001. Department of Health and Human Services, Public Health Service, Food and Drug Administration, Center for Food Safety and Applied Nutrition, Office of Seafood, Washington, DC. 2002.
100. Brilliantes S, Samosorn W. Determination of histamine in fish sauce from Thailand using a solid phase extraction and high-performance liquid chromatography. Fish Sci. 2001;67:1163–8.
101. Auerswald L, Morren C, Lopata AL. Histamine levels in seventeen species of fresh and processed South African seafood. Food Chem. 2006;98:231–9.
102. Zhang J, Liu Z, Hu Y, Fang Z, Chen J, Wu D, Ye X. Effect of sucrose on the generation of free amino acids and biogenic amines in Chinese traditional dry-cured fish during processing and storage. J Food Sci Technol. 2011;48(1):69–75.
103. Mar JH, Hwang HJ. Inhibition of biogenic amine formation in a salted and fermented anchovy by *Staphylococcus xylosus* as a protective culture. Food Control. 2009;20:796–801.
104. Surya R, Megumi EH, Nugroho D, Tedjakusuma F, Rombot O. Supplementation of *Moringa oleifera* leaves improves the safety and quality of fermented shrimp paste. 6th ICoFA IOP Publishing 2024; 1338, 012034. https://doi.org/10.1088/1755-1315/1338/1/012034
105. Kouakou AC, N'Guessan KF, Durand N, Thomas DA, Montet D, Djè MK. Molecular bacterial characterization and free amino acids composition in Ivorian traditional fermented fish produced by two methods. Fish Sci. 2012;2012(78):1125–36.