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Review

Occurrence and reduction of biogenic amines in traditional Asian fermented soybean foods: A review

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ABSTRACT

Biogenic amines are harmful substances generated during the fermentation process. Regulations on biogenic amine content in fermented foods are currently insufficient in comparison to the popularity of fermented food consumption in Asian countries. The current review evaluated the biogenic amine content of fermented soybean-based Asian foods to determine whether the food products are safe for consumption. Though the reported ranges of biogenic amine content in fermented soybean foods varied widely, most products contained biogenic amine concentrations at potentially hazardous levels. To ensure the safety of fermented soybean food products, further efforts are required in the improvement of the food manufacturing process, as well as the establishment of regulations on managing biogenic amine content.

1. Introduction

The production and consumption of fermented soybean products have been a traditional practice of many Asian countries (Mah, 2015). Though the origin of fermented soybean products are unclear, methods of production have been recorded in the *Cheminyoshul*, a Chinese agriculture manuscript dating back as early as 530–550 CE. Other records, such as the Korean manuscript *Samkuksaki*, date back to the Goryeo dynasty, which indicates that fermented soybeans were likely consumed during the 12th century (Cho & Lee, 1970; Yoon et al., 1990). The ubiquitous consumption of fermented soybean products in Asian countries may be attributed to the widespread adoption of soybean cultivation. Though native to the Manchuria region, soybeans later spread across northeastern Asian countries (An, 2002). As the highly adaptable crops were well-suited for cultivation in a wide variety of climates and geographical regions, soybeans were quickly regarded as a staple food in the region (Hymowitz, 1970; Wu, Schenk-Hamlin, Zhan, Ragsdale, & Heimpel, 2004). As a result, the adoption of the staple food in Asian countries led to the production of many soybean-based fermented foods. In addition, fermented soybean foods played a vital role as a protein source in the traditional grain-based Asian diet, which typically involved insufficient meat consumption (Park, Hwang, Jung, & Lee, 2002). The most popular fermented soybean products include soy sauce in Asian countries, *Gochujang* (fermented red pepper paste), *Doenjang* (fermented soybean paste), and *Cheonggukjang* (fermented whole soybean pastes) in Korea, *Natto* (fermented soybeans) and *Miso* (fermented soybean paste) in Japan, as well as *Douchi* (fermented black soybeans), and *Doubanjiang* (chili bean sauce) in China (Yoon, 2007). The multitude of health benefits and functionality of fermented soybean products have been well documented in numerous studies, as previous reports described health benefits which include anti-carcinogenic properties, mediation of glucose uptake, thrombolytic properties, promotion of probiotics beneficial for the digestive system, and inhibition of harmful bacteria in the gastrointestinal tract (Lim, Rhee, & Park, 2004; Youn & Kim, 2012). Moreover, consumption of fermented soybeans also promote digestion and intestinal regulation (Park, 2012). Recognized globally for its functionality and distinctive flavours, “fermented soybean pastes” are even listed in the Codex Alimentarius Commission (CODEX).

Nevertheless, harmful bacteria may produce potentially toxic metabolites during fermentation (Park, 2012), including nitrogenous compounds known as biogenic amines (BA). BA are formed mostly through enzymatic amino acid decarboxylation, as well as reductive amination of ketones and aldehydes (Askar & Treptow, 1986). As seen in Fig. 1, BA are often categorized as aliphatic: putrescine, cadaverine, agmatine, spermine, spermidine; aromatic: tryptamine, β-phenylethylamine; heterocyclic: histamine and tryptamine (Shukla, Kim, & Kim, 2011; Ten Brink, Damink, Joosten, & Huis in 't Veld, 1990). Among BA, polyamines that naturally occur in fruits, vegetables, and legumes are involved in biological processes, such as cell growth and organogenesis in plants (Kalac & Krausová, 2005). Regardless, the ingestion of BA in high concentrations as well as the deficiency or inhibition of amine

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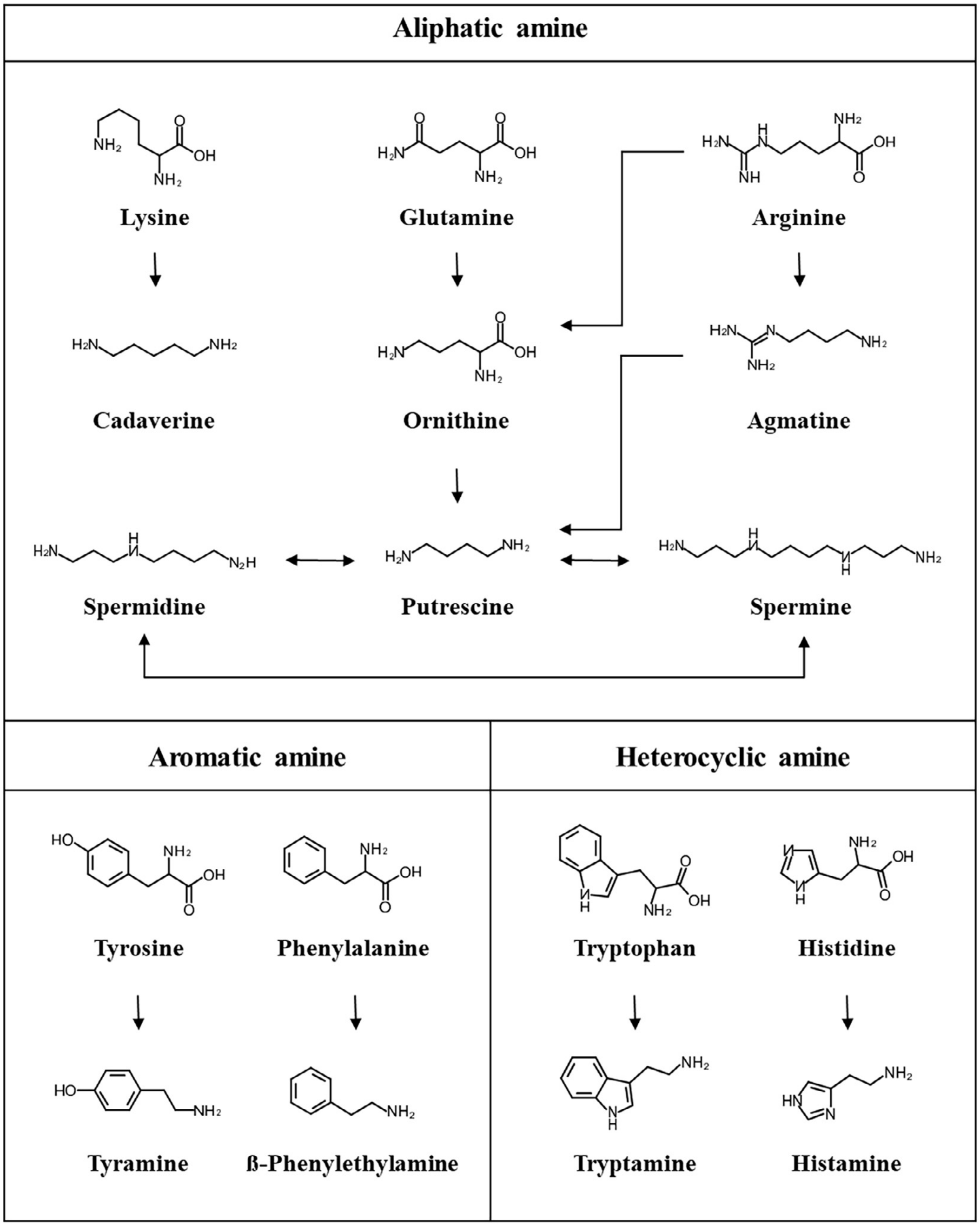

Fig. 1. Structure of biogenic amines and respective precursors.

oxidases may potentially lead to toxic effects (Gilbert, Hobbs, Murray, Cruickshank, & Young, 1980). Though BA are usually detoxified through monoamine oxidase (MAO) and diamine oxidase (DAO) in the small intestine, potentiation of toxic effects may occur by over-saturation of amine oxidases with high concentrations of BA, use of monoamine oxidase inhibitors (MAOI), or consumption of alcohol (Shalaby, 1996; Taylor, 1986). As one of the most toxic amines, excessive intake of foods which contain high concentrations of histamine, such as mackerel, pacific saury, sardines, and tuna, may result in scombroid poisoning with symptoms similar to allergic reactions, such as dyspnea, headache, hives, diarrhea, and hypotension (Taylor, 1986). As a vasoactive amine, tyramine may potentially cause a "cheese crisis" with symptoms such as raised blood pressure, severe headaches, hypertensive crisis, haemorrhages, and heart failure (Smith, 1981). Furthermore, BA may also be converted to potentially carcinogenic N-nitrosamines in the presence of nitrites (Shalaby, 1996; Smith, 1981).

The potential food safety issues especially in regards to BA produced during the fermentation process are generally overlooked as fermented foods have established a reputation for functionality and health benefits. Furthermore, few studies have been conducted on Asian foods relative to the research conducted on the BA content of popular Western foods, such as fermented sausages or cheeses (Kim, Park, Kim, Ahn, & Byun, 2003). In this review paper, the BA content of traditional Asian fermented soybean foods as reported in previous studies were investigated and evaluated.

2. Regulation of biogenic amines

The US FDA has set a guidance level of 50 mg/kg for histamine in the edible portion of fish (FDA, 2011), and the EFSA panel has suggested fish containing less than 50 mg/kg is safe for consumption (EFSA, 2011). Restrictions on BA content in seafood for both South Korea and China imposes maximum limits of histamine content in fish, such as Scrombridae, at 200 mg/kg and 200–400 mg/kg, respectively. Currently, there are no clear regulatory standards for monitoring BA in fermented soybean foods, as most efforts are focused primarily on fish and seafood products. Previous studies have suggested toxic limits for BA at 30 mg/kg for β-phenylethylamine, 100 mg/kg for histamine, 100–800 mg/kg for tyramine (Ten Brink et al., 1990), and 1000 mg/kg for total BA content (Santos, 1996). Thus, the BA content of fermented soybean products were evaluated according to the BA intake limits (30 mg/kg for β-phenylethylamine, 100 mg/kg for histamine, and 100 mg/kg for tyramine) suggested by Ten Brink et al. (1990).

3. Biogenic amine content of fermented soybean products in Asian countries

3.1. Korea

Major fermented soybean products in Korea include *Cheonggukjang*, *Doenjang*, *Gochujang* and Korean soy sauce. *Cheonggukjang* is classified based upon whether modern or traditional methods are used for production. Though production methods typically include a short fermentation period of 2–3 days, rice straw is added to steamed soybeans during traditional *Cheonggukjang* production, while modern methods utilize starter cultures instead (Jang et al. 2006; Kim, Ryu, & Kim, 1982). The degradation of proteins by microbial enzymatic activity during fermentation yields unique savory olfactory and gustory properties that are characteristic of the traditional Korean fermented food (Hong, Kim, Lee, & Chung, 2006). However, various studies have reported the BA content of Korean fermented soybean products as seen in Table 1. Though Cho et al. (2006) and Han et al. (2007) have reported *Cheonggukjang* histamine concentrations at levels below limits suggested by Ten Brink et al. (1990), both studies reported tyramine content that exceeded recommended limits for safe consumption by a factor of 5. In addition, Jeon, Lee, and Mah (2018) reported β-phenylethylamine, histamine, and tyramine content that exceeded recommended toxicity limits by a factor of approximately 19, 4, and 3, respectively. In comparison, Ko et al. (2012) reported even higher BA concentrations, as histamine and tyramine concentrations well exceeded the recommended limits by a factor of 8 and 19, respectively. The variation in the BA content of fermented soybean products may be due to factors such as differences in the production process and microorganisms responsible for fermentation. Although *B. subtilis* present in rice straw are primarily responsible for *Cheonggukjang* fermentation, BA content have been suggested to vary due to the presence of other microorganisms (Cho et al., 2006; Ko et al., 2012). Consequently, standardized starter cultures are necessary to minimize BA content during fermentation (Lee, Cho, Park, Kim, & Hahm, 2010).

Similar to *Cheonggukjang*, *Doenjang* is classified according to whether traditional or modern methods were used for production. Traditional methods of *Doenjang* fermentation utilize microorganisms, such as *Bacillus subtilis* and fungal spp., naturally present in the ingredients. The main ingredient is known as *Meju*, which is prepared by crushing and compressing steamed soybeans into bricks (Park et al., 2002). The *Meju* is then dried, bundled with rice straw, and fermented for 2–3 months. Afterwards, the fermented *Meju* is immersed in brine and aged for 2–3 months to produce *Doenjang* (soybean paste) and Korean soy sauce. Modern *Doenjang* is prepared by inoculating a mixture of *Aspergillus oryzae* and wheat flour onto steamed soybeans, followed by the addition of brine before undergoing fermentation for 45–60 days (Park et al., 2002). Several studies have reported that BA may be formed during *Doenjang* fermentation. According to previous reports by Cho et al. (2006), Lee, Kim, and Lee (2009) and Kim et al. (2011) the β-phenylethylamine, histamine and tyramine content of *Doenjang* exceeded the recommended limits for consumption by a factor of approximately 2-18, 3-10, and 10-14, respectively. Shukla, Park, Kim, and Kim (2010) in particular reported BA content at significantly higher levels, as the reported β-phenylethylamine, histamine and tyramine concentrations exceeded other reports by a factor of approximately 16, 3, and 5, respectively. Compared to other studies, both Lee, Oh, Kim, and Kim (2013) and Yoon, Kim, and Moon (2017) reported the BA content of *Doenjang* at significantly lower levels. Lee et al. (2013) reported tyramine concentrations which slightly exceeded the 100 mg/kg limit, though the remaining BA concentrations were reported at concentrations lower than 100 mg/kg. As for BA concentrations reported by Yoon et al. (2017), while most BA concentrations did not exceed 100 mg/kg, β-phenylethylamine levels exceeded the recommended toxicity limit by a factor of 2. The BA content of *Doenjang* was also reported to vary depending on the production method, as according to Cho et al. (2006), the use of *Meju* in traditional fermentation methods yielded *Doenjang* with higher BA content than

Table 1
Biogenic amine content of Korean fermented soybean products.

Fermented soybean products	N[a]	Biogenic amine content (mg/kg)[b]								References
		Trp	Phe	Put	Cad	His	Tyr	Spd	Spm	
Cheonggukjang	7	6.7–236.4[c]	ND[d]-40.8	4.7–121.3	2.1–20.2	1.3–54.3	0.7–483.1	39.6–59.2	7.1–14.7	Cho et al. (2006)
	10	6.7–76.9	ND-32.6	4.7–148.5	4.6–70.6	0.2–70.3	4.2–483.1	33.4–67.7	7.2–23.1	Han et al. (2007)
	102	NT[e]	NT	NT	NT	ND-755.40	ND-1913.51	NT	NT	Ko et al. (2012)
	60	2.64–231.98	0.12–562.44	0.12–476.30	ND-268.16	ND-408.74	ND-251.66	ND-79.05	ND-20.89	Jeon et al. (2018)
Doenjang	14	6.1–234.1	ND-529.2	9.9–1453.7	0.3–65.4	1.5–952.0	3.4–1430.7	4.2–23.4	ND-10.2	Cho et al. (2006)
	10	ND-449.8	ND-544.0	28.8–1076.6	2.7–144.1	1.4–329.2	12.5–967.6	ND-30.3	ND-9.8	Lee et al. (2009)
	23	ND-2808.1	ND-8704.6	ND-4292.3	ND-3235.5	ND-2794.8	ND-6616.1	ND-8804.0	ND-9729.5	Shukla et al. (2010)
	7	13.5–45.9	3.3–65.0	46.7–168.2	ND-12.9	71.1–382.4	46.4–1190.7	ND-24.7	NT	Kim et al. (2011)
	8	1.0–11.1	0.1–20.2	4.6–55.2	0.9–18.4	3.3–83.7	3.1–126.9	0.1–2.8	NT	Lee et al. (2013)
	14	ND-192.29	ND-71.67	ND-180.74	ND	ND-12.81	ND-25.11	ND-11.30	ND-7.21	Yoon et al. (2017)
Gochujang	5	17.9–36.6	0.7–9.1	2.5–3.2	ND-1.1	0.6–1.3	2.1–4.9	1.6–3.4	1.4–1.8	Cho et al. (2006)
	7	ND-8.1	1.5–24.8	10.4–36.4	ND-18.1	2.2–59.0	2.9–126.8	ND-14.5	NT	Kim et al. (2011)
	8	0.1–4.1	0.5–2.0	0.3–2.6	0.1–0.4	0.4–7.8	0.2–27.2	0.1–1.3	NT	Lee et al. (2013)
Soy sauce	1	0.094	0.477	11.953	0.082	1.282	0.867	NT	0.391	Kim et al. (2003)

[a] Quantity of samples examined.
[b] Trp: tryptamine, Phe: β-phenylethylamine, Put: putrescine, Cad: cadaverine, His: histamine, Tyr: tyramine, Spd: spermidine, Spm: spermine.
[c] The range from minimum to maximum. The same number of digits is used after the decimal point in the values, as was presented in the corresponding references.
[d] ND: Not detected.
[e] NT: Not tested.

fermentation with starter cultures utilized by modern methods. Instead of *Meju* used in traditional methods, modern *Doenjang* production utilizes other starch sources, such as wheat flour, rice, and barley. Modern production methods also utilizes less soybeans for *Doenjang* production, which may account for the lower BA content (Park et al., 2002). As the BA content of *Doenjang* were found to vary widely, even when produced by the same company, improvements in the production process, as well as the use of standardized starter cultures, appear to be necessary (Cho et al., 2006).

Gochujang preparation utilizes a combination of glutinous rice, *Meju* powder, red pepper powder, and salt to yield the complementary sweet, savory, salty, and spicy flavours that are characteristic of the traditional Korean food (Cho, Park, & Kim, 1981). The BA content of *Gochujang* has been reported by Cho et al. (2006) and Lee et al. (2013) at concentrations less than 50 mg/kg. Though Kim et al. (2011) also reported similar low levels of BA, tyramine content was observed in excess of 126.8 mg/kg, which exceeded the recommended limit of 100 mg/kg.

As a staple condiment, Korean soy sauce is produced by combining steamed soybeans with brine, and upon fermentation, the soybeans are extracted while the remaining liquid is filtered (Luh, 1995). Kim et al. (2003) reported the BA concentrations of retail soy sauce at safe concentrations lower than 20 mg/kg for each of the 8 amines tested, well below the recommended limits for consumption.

3.2. China

The main fermented soybean products consumed in China include *Chunjang*, *Doubanjiang*, *Douchi*, *Sufu*, and Chinese soy sauce. Known as *Tianmianjiang* in China, or *Chunjang* in Korea, sweet bean sauce is produced by fermenting steamed soybeans, flour, and salt followed by subsequent caramelization. As presented in Table 2, the BA content of Chinese fermented soybean products are shown. Bai, Byun, and Mah (2013) reported the histamine content of *Chunjang* from Korean retail markets at concentrations that exceeded the toxicity limits by a factor of approximately 3, while tyramine content slightly exceeded the recommended limit. The other remaining BA were detected at safe levels below 30 mg/kg. The BA content reported by Cho et al. (2006) were detected at safe concentrations lower than the recommended limits for consumption.

The fermented soybeans used in *Doubanjiang* undergo a process similar to *Doenjang*, as the beans are not completely crushed during production (Yoon, 2007). The BA content of *Doubanjiang* as reported by Byun, Bai, and Mah (2013) showed that while 6 of the 7 products sampled contained BA content lower than 100 mg/kg for all 8 amine tested, one sample contained β-phenylethylamine content at concentrations that exceeded the recommended limit by a factor of approximately 6.

Douchi is produced using *Aspergillus*, *Mucor*, *Rhizopus*, or bacteria inoculated onto steamed black soybeans for solid-state fermentation, followed by salt treatment and further maturation (Chen, Cheng, Yamaki, & Li, 2007). The biogenic content of *Douchi* as reported by both Tsai, Kung, Chang, Lee, and Wei (2007) and Yang, Ding, Qin, and Zeng (2014) for β-phenylethylamine, histamine, and tyramine exceeded recommended limits by a factor of approximately 8-25, 5-8, and 3-5, respectively. In contrast, in a study by Gong et al. (2014), β-phenylethylamine, histamine, and tyramine were not detected in *Douchi*. The BA content varied between different varieties of *Douchi*, particularly for black bean *Douchi*, which contained at least twice the BA content of regular *Douchi* for nearly every amine tested (Tsai, Kung et al., 2007). An important factor that affected BA content was the microbial inoculant used for fermentation. *Douchi* produced with bacteria were found to contain BA content less than 100 mg/kg for each amine, however both *Aspergillus*-type and *Mucor*-type *Douchi* contained β-phenylethylamine, histamine, and tyramine content at concentrations that exceeded recommended limits (Yang et al., 2014). The reported results were unexpected as few studies have been conducted on fungal BA production (Nout, Ruikes, Bouwmeester, & Beljaars, 1993).

Sufu is produced by inoculating molds and bacteria onto tofu, followed by salting, and ripening in dressing for at least 3 months (Han, Rombouts, & Nout, 2001). The type of dressing used determines the colour, and subsequently the category of *sufu*. While the main *Sufu* varieties include red (which contains red rice koji, a koji prepared with Monascus purpureus), white, and gray *Sufu* (without red rice koji), other varieties produced include brown, sesame oil, hot, and alcoholic *Sufu* (Han et al., 2001; Qiu et al., 2018; Wai, 1929). As reported by Qiu et al. (2018), Toro-Funes, Bosch-Fuste, Latorre-Moratalla, Veciana-Nogués, and Vidal-Carou (2015), Gong et al. (2014), Guan et al. (2013), Kung, Lee, Chang, Wei, and Tsai (2007), and Yang et al. (2014) the BA content of *Sufu* for β-phenylethylamine, histamine, and tyramine exceeded recommended toxicity limits by a factor of approximately 0-11, 2-12, and 1-17, respectively. Conversely, Tang et al. (2011) reported *Sufu* BA content at safe levels below recommended limits. Major

Table 2
Biogenic amine content of Chinese fermented soybean products.

Fermented soybean products	N[a]	Biogenic amine content (mg/kg)[b]								References
		Trp	Phe	Put	Cad	His	Tyr	Spd	Spm	
Chunjang	4	13.3–19.9[c]	2.2–11.8	9.2–11.7	1.7–6.6	11.6–22.4	29.7–54.6	1.4–12.8	ND[d]-2.9	Cho et al. (2006)
	4	19.57–31.35	ND-6.79	3.26–28.59	ND-2.04	1.85–272.55	19.78–131.27	0.24–11.63	ND-1.49	Bai et al. (2013)
Doubanjiang	7	ND-62.43	1.43–185.61	1.15–129.17	ND-0.17	ND	ND-25.75	ND-0.18	ND-1.69	Byun et al. (2013)
Douchi	26	ND-440	ND-239	ND-596	ND-191	ND-808	ND-529	ND-719	ND-242	Tsai, Kung et al., 2007
	30	ND-69.56	ND-736.64	ND-276.03	ND-672.33	ND-478.77	ND-252.08	ND-74.92	ND	Yang et al. (2014)
	8	ND–28.6	ND	1.6–43.2	23.4–228.1	ND	ND	ND	ND	Gong et al. (2014)
Sufu	22	ND-81	ND	ND-45	ND-371	ND-158	ND-65	ND	ND-82	Kung, Lee et al. (2007)
	10	26.6–57.0	ND-4.2	21.2–47.3	NT[e]	ND-40.2	ND-48.0	ND-27.1	ND-22.9	Tang et al. (2011)
	38	ND-104.1	ND-36.3	0.5–316.9	0.6–85.8	ND-196.9	ND-446.6	ND-4.0	ND-6.9	Guan et al. (2013)
	33	ND-463.45	ND-341.03	11.38–1147.32	ND-308.44	ND-415.38	ND-549.34	ND	ND	Yang et al. (2014)
	3	ND	1.69–4.27	9.33–18.76	33.39–36.96	127.6–730.0	910.6–1730	ND-1.36	0.88–2.21	Toro-Funes et al. (2015)
	8	1.7–31.0	ND	32.5–256.7	87.5–310.6	51.9–505.8	13.2–197.1	ND	8.4–24.9	Gong et al. (2014)
	16	ND-469.87	ND-110.14	8.53–1244.86	6.84–83.42	ND-1186.93	11.25–1537.38	ND-32.87	ND-7.70	Qiu et al. (2018)
Soy sauce	40	NT	NT	NT	ND-550	ND-592	ND-673	ND-486	ND-145	Yongmei et al. (2009)

[a] Quantity of samples examined.
[b] Trp: tryptamine, Phe: β-phenylethylamine, Put: putrescine, Cad: cadaverine, His: histamine, Tyr: tyramine, Spd: spermidine, Spm: spermine.
[c] The range from minimum to maximum. The same number of digits is used after the decimal point in the values, as was presented in the corresponding references.
[d] ND: Not detected.
[e] NT: Not tested.

differences in BA concentrations were observed depending on the *Sufu* variety. As reported by Qiu et al. (2018), Yang et al. (2014), and Guan et al. (2013), the BA content of red *Sufu* were detected at safe concentrations below the recommended limits. Kung, Lee et al. (2007) reported histamine concentrations were approximately 8 times higher in brown *Sufu* than white *Sufu*. According to Qiu et al. (2018), hot *Sufu* was reported to contain the highest concentration of BA, exceeding the recommended limits for β-phenylethylamine, histamine, and tyramine by factor of approximately 4, 12, and 15, respectively. In addition, sesame oil *Sufu* was also reported to contain BA content in excess of approximately 2, 11, and 14 times higher than the recommended limits for β-phenylethylamine, histamine, and tyramine, respectively. Alcoholic *Sufu* also contained β-phenylethylamine and tyramine content at concentrations that exceeded the recommended limits by a factor of approximately 2 and 6, respectively. There are many varieties of *Sufu* compared to other fermented products, however histamine and tyramine content was reported at levels that consistently exceeded the recommended limits. Therefore, as *Sufu* fermented in an open environment and stored at room temperature yielded high BA content, improving the sanitary conditions, as well as standardization of the manufacturing process, may be necessary to reduce BA formation (Guan et al. 2013).

The BA content of Chinese soy sauce as reported by Yongmei et al. (2009) indicated that histamine and tyramine content exceeded recommended limits by a factor of approximately 6 and 7, respectively. An analysis of 40 soy sauce samples indicated that the histamine content of 24 samples had not exceeded the recommended limit of 100 mg/kg, however the remaining 16 samples exceeded the recommended limit for histamine, indicating the potential for toxicity. Similarly, the tyramine content of 22 samples were determined to contain less than the 100 mg/kg limit, though the remaining 18 samples contained concentrations that exceeded the recommended limit for tyramine.

3.3. Japan

The major fermented soybean products in Japan include *Miso*, *Natto*, and Japanese soy sauce. *Miso* is a common food and seasoning used in Japanese cuisine that is produced using *Aspergillus oryzae to* inoculate steamed soybeans, rice and barley, which is subsequently mixed with salt upon fermentation (Murooka & Yamshita, 2008). The biogenic amine content of Japanese fermented soybean products are shown in Table 3. Cho et al. (2006), Byun and Mah, (2012), and Toro-Funes et al. (2015) all reported *Miso* BA content at safe concentrations lower than the recommended limits for consumption. In contrast, Kung, Tsai, and Wei (2007) reported histamine content of *Miso* at concentrations that exceeded the recommended limit by a factor of 2, while Shukla, Park, Kim, and Kim (2011) observed β-phenylethylamine content at levels slightly above the threshold for toxicity.

Natto is produced by fermenting steamed soybeans with *B. subtilis* for a short duration of approximately 20 h (Murooka & Yamshita, 2008). Toro-Funes et al. (2015) reported the BA content of *Natto* at safe concentrations lower than the recommended limits for consumption. Conversely, Tsai, Chang, and Kung (2007) reported histamine content at concentrations that exceeded the recommended limit by a factor of 5, while Kim, Byun and Mah (2012) reported β-phenylethylamine and tyramine content at concentrations that exceeded the corresponding limits by a factor of approximately 2 and 3, respectively. Though spermidine and spermine content in *Natto* products was reported in relatively high concentrations, the BA content may originate from the soybeans used for *Natto* production (Kalac & Krausová, 2005).

According to Kim et al. (2003) the BA content of 8 Japanese retail soy sauce products were reported at safe concentrations under 20 mg/kg for each amine, well under the recommended limits for consumption. *Tamari* soy sauce is a Japanese variant that is produced primarily with soybeans (occasionally with small quantities of wheat) inoculated with *Shoyu* koji to ferment for an extended duration (Kataoka, 2005). Toro-Funes et al. (2015) reported the BA content of *Tamari* soy sauce at safe concentrations below the recommended limits for consumption. Nevertheless, compared to soy sauce normally brewed with wheat, the higher BA levels in *Tamari* soy sauce may be due to the greater amount of soybeans used during fermentation (Kataoka, 2005).

3.4. Indonesia

Among studies on Indonesian fermented soybean foods, only the BA content of *Tempeh* have been reported. Traditional Indonesian *Tempeh* is produced using soaked dehulled beans inoculated with the fungus *Rhizopus* to ferment at 30–40 C for 24–36 h (Nout, De Dreu, Zuurbier, & Bonants-Van Laarhoven, 1987). As seen in Table 4, the BA content of *Tempeh* as reported by Nout et al. (1993) indicated that histamine levels slightly exceeded the recommended toxicity limit while tyramine content exceeded the recommended limit by a factor of 5-6. Conversely, Saaid, Saad, Hashim, Ali, and Saleh (2009) and Toro-Funes et al. (2015) reported the BA content of *Tempeh* at levels below the recommended limits for consumption.

4. Biogenic amine production by microorganisms isolated from fermented soybean products

BA are mainly produced by microbial decarboxylation of free amino acids (Ten Brink et al., 1990). Various microorganisms are capable of producing decarboxylases which include Enterobacteriaceae, *Bacillus*, *Clostridium*, *Lactobacillus*, and *Pseudomonas* (Rice, Eitenmiller, & Koehler, 1976; Rodriguez-Jerez, Giaccone, Colavita, & Parisi, 1994). The decarboxylase activity of microorganisms in fermented soybean foods were analyzed using various assay media containing precursor amino acids. Table 5 shows the BA production by bacteria isolated from fermented soybean food products. Production of amino acid decarboxylases by *Bacillus* spp. isolated from *Cheonggukjang* have been reported for *B. subtilis* which decarboxylated histidine, *B. licheniformis* that decarboxylated tyrosine and lysine, and *B. amyloliquefaciens* which decarboxylated histidine, tyrosine, ornithine and lysine. The production of decarboxylases by *B. amyloliquefaciens* was further substantiated as the strain produced the highest amount of BA in assay media (Han et al., 2007). Jeon et al. (2018) reported that *Bacillus* spp. produced histamine and tyramine at concentrations ranging from ND-297.87 μg/ml and ND-123.08 μg/ml in assay media, respectively. According to Kung, Lee et al. (2007), Kung, Tsai et al. (2007), Bai et al. (2013), and Tsai, Chang et al. (2007), various species of bacteria isolated from fermented soybean products, such as *B. subtilis*, *B. amyloliquefaciens*, *B. megaterium*, did not produce high concentrations of BA in assay media, however all isolates displayed histamine production capabilities. The results suggest that BA production by *Bacillus* spp. may contribute to the histamine content of fermented soybean foods. Compared to *Bacillus* spp., *Enterococcus* spp. had exhibited higher levels of tyramine production at 0.41–351.59 μg/ml in assay media (Jeon et al., 2018). A previous study has also reported that Enterobacteriaceae or Enterococci may produce BA in contaminated food products (Novella-Rodríguez, Veciana-Nogues, Roig-Sagues, Trujillo-Mesa, & Vidal-Carou, 2004). Apart from bacteria related to fermentation, Tsai, Kung et al. (2007) reported that *Staphylococcus capitis* isolated from *Douchi* samples produced histamine at concentrations of 238–601 μg/ml in assay media. Prevention of contamination, sanitary practices, and utilization of starter cultures are necessary to reduce microbial BA production and in turn control BA accumulation during fermented food production.

5. Reduction of biogenic amines in fermented soybean products

Current research focuses on the development of starter cultures to reduce BA in fermented soybean foods. Oh et al. (2014) reported that compared to the uninoculated control, *Pediococcus pentosaceus* strains isolated from *Cheonggukjang* were able to degrade histamine and

Table 3
Biogenic amine content of Japanese fermented soybean products.

Fermented soybean products	N[a]	Biogenic amine content (mg/kg)[b]								References
		Trp	Phe	Put	Cad	His	Tyr	Spd	Spm	
Miso	5	21.6–23.7[c]	0.7–8.1	16.4–23.2	2.8–3.2	0.8–1.1	2.0–95.3	9.5–21.9	1.3–3.1	Cho et al. (2006)
	40	ND[d]-762	ND	ND-12	ND-201	ND-221	ND-49	ND	ND-216	Kung, Tsai et al. (2007)
	6	NT[e]	NT	19.75–34.29	NT	NT	NT	0.44–5.96	ND-6.27	Nishibori, Fujihara, and Akatuki (2007)
	8	ND-1.3	ND-42.0	ND-12.9	ND-8.7	ND	ND-41.9	ND-35.7	ND	Shukla et al. (2011)
	22	ND-9.71	2.38–11.76	2.69–14.09	ND-1.31	ND-24.42	ND-66.66	ND-28.31	ND-2.85	Byun and Mah (2012)
	3	ND	ND	2.73–17.81	ND-3.83	1.49–4.62	ND	7.54–9.91	2.54–3.54	Toro-Funes et al. (2015)
Natto	NA[f]	NT	NT	11.37	203.34	NT	NT	87.15–153.97	17.81	Nishimura, Shiina, Kashiwagi, and Igarashi (2006)
	39	ND-301.0	ND	ND-27.0	ND-42.0	ND-457.0	ND-45.0	ND-124.0	ND-71.0	Tsai, Chang et al. (2007)
	21	ND-45.80	ND-51.50	ND-43.10	ND-36.80	ND-34.40	ND-300.20	246.50–478.10	18.80–80.10	Kim et al. (2012)
	3	ND	ND	5.81–9.49	2.79–5.43	ND	ND	56.91–75.21	9.17–11.15	Toro-Funes et al. (2015)
Soy sauce	8	ND-0.408	0.195–2.499	0.908–17.832	ND-0.429	0.249–2.283	0.139–11.112	NT	0.132–0.849	Kim et al. (2003)
	NA	NT	NT	26.8	36.17	NT	NT	12.93	ND	Nishimura et al. (2006)
	6	NT	NT	29.79–136.37	NT	NT	NT	6.25–16.70	0.2–3.84	Nishibori et al. (2007)
Tamari soy sauce	NA	NT	NT	30.32	39.85	NT	NT	15.4	ND	Nishimura et al. (2006)
	3	10.35–12.57	9.91–11.26	13.07–17.08	1.23–1.81	38.11–57.65	40.19–76.66	29.45–38.02	2.78–6.77	Toro-Funes et al. (2015)

[a] Quantity of samples examined.
[b] Trp: tryptamine, Phe: β-phenylethylamine, Put: putrescine, Cad: cadaverine, His: histamine, Tyr: tyramine, Spd: spermidine, Spm: spermine.
[c] The range from minimum to maximum. The same number of digits is used after the decimal point in the values, as was presented in the corresponding references.
[d] ND: Not detected.
[e] NT: Not tested.
[f] NA: Not available.

Table 4
Biogenic amine content of Indonesian fermented soybean products.

Fermented soybean products	N[a]	Biogenic amine content (mg/kg)[b]								References
		Trp	Phe	Put	Cad	His	Tyr	Spd	Spm	
Tempeh	2	< 5	NT[c]	475-3200[d]	< 5–225	< 5–100	500–575	NT	NT	Nout et al. (1993)
	NA[e]	NT	NT	45.31	35.15	NT	NT	85.55	13.56	Nishimura et al. (2006)
	1	15.6	NT	116.9	NT	4.1	4.3	11.6	NT	Saaid et al. (2009)
	3	ND[f]	ND	17.53–31.06	1.52–7.21	ND	ND-10.68	97.3–105.5	6.06–21.89	Toro-Funes et al. (2015)

[a] Quantity of samples examined.
[b] Trp: tryptamine, Phe: β-phenylethylamine, Put: putrescine, Cad: cadaverine, His: histamine, Tyr: tyramine, Spd: spermidine, Spm: spermine.
[c] NT: Not tested.
[d] The range from minimum to maximum. The same number of digits is used after the decimal point in the values, as was presented in the corresponding references.
[e] NA: Not available.
[f] ND: Not detected.

tyramine *in vitro* by 14.7–23.7% and 15.7–25.9%, respectively. Compared to the *B. subtilis* type strain, other strains isolated from *Cheonggukjang*, such as *B. subtilis* and *B. amyloliquefaciens*, were capable of reducing tyramine content *in vitro* and *in situ* by 30.75–39.50% and 39.18–65.76%, respectively (Kang, Lee, & Hwang, 2017). Kim, Cho, Jeong, and Uhm (2012) also isolated BA-degrading *B. subtilis* and *B. amyloliquefaciens* from *Doenjang*, *Cheonggukjang*, and *Gochujang* with varied BA degradation capabilities even among the same species. Compared to the uninoculated control, the isolated *B. subtilis* strains were reported to degrade histamine and tyramine *in vitro* by 27–46% and 42–59%, respectively. Similarly, *in vitro* histamine and tyramine degradation by the *B. amyloliquefaciens* strain were observed at 70% and 71%, respectively. According to Lee et al. (2016), compared to the control without inoculants, *Miso* inoculated with *L. plantarum* as a starter culture had lowered histamine and total BA content by 58% and 27%, respectively. Similarly, Kung et al. (2017) also reported *L. plantarum* in *Miso* degraded histamine by 66.7–100%, when compared to the uninoculated control.

The use of additives to reduce BA content in fermented soybean foods have also been reported. Qiu et al. (2018) reported significantly lower BA content of *Sufu* prepared with dressing mixures that included ethanol. Kang, Kim, Mah, Kim, and Hwang (2018) conducted research on reducing tyrosine decarboxylase activity of *Enterococcus faecium* isolated from *Cheonggukjang*, and found that compared to the control without any additives, nicotinic acid reduced *Enterococcus* cell counts *in vitro* as well as tyramine *in vitro* and *in situ*.

Although studies have reported on methods to reduce BA content *in vitro* and *in situ*, practical application is necessary to ensure the production of safe fermented food products.

6. Conclusions

The current study evaluated the BA content of fermented soybean foods originating mostly from Korea, China, Japan, and Indonesia. Fermented soybean products were generally reported to contain high concentrations of BA. The consumption of food products containing high amounts of BA may result in adverse effects on the body. Large fluctuations in the BA content of fermented soybean products indicated a need for standardization in the methods of fermented food production. Improvements in the food manufacturing process are necessary to

Table 5
Biogenic amine production by bacteria isolated from fermented soybean food products.

Fermented soybean products	Strain	N[a]	Biogenic amines (μg/mL)[b]								References
			Trp	Phe	Put	Cad	His	Tyr	Spd	Spm	
Cheonggukjang	*Bacillus subtilis*	NA[c]	NT[d]	NT	122.9–1831.3[e]	111.0–1838.4	204.7–2326.4	151.6–1927.7	NT	NT	Han et al. (2007)
	B. amyloliquefaciens	NA	NT	NT	98.5–1908.7	285.9–1927.0	227.7–2305.5	229.4–2122.1	NT	NT	
	B. ilcheniformis	NA	NT	NT	27.5–1218.8	186.7–2242.3	22.4–1308.7	335.4–2524.5	NT	NT	
	Bacillus spp.	433	ND[f]-6.98	ND-19.76	ND-261.31	ND-288.98	ND-297.87	ND-123.08	ND-0.93	ND-33.75	Jeon et al. (2018)
	Enterococcus spp.	55	ND-6.19	ND-5.43	ND-1.31	ND-0.76	ND-1.54	0.41–351.59	ND-52.69	ND-1.24	
Chunjang	Bacterial strains	89	0.45 ± 0.32[g]	0.85 ± 0.23	0.95 ± 0.55	ND	1.34 ± 1.19	1.41 ± 0.32	9.26 ± 5.73	2.17 ± 1.09	Bai et al. (2013)
Doubanjiang	*B. subtilis*	NA	0.20 ± 0.45	0.67 ± 1.42	3.45 ± 1.29	1.03 ± 0.46	0.22 ± 0.65	0.59 ± 0.65	0.40 ± 0.20	1.29 ± 0.86	Byun et al. (2013)
Douchi	*B. subtilis*	4	NT	ND-9.0	NT	ND-1.0	11.7–32.4	ND-1.0	NT	ND-7.8	Tsai, Kung et al. (2007)
	Staphylococcus pasteuri	1	NT	ND	NT	1.2	20.0	ND	NT	ND	
	S. capitis	3	NT	ND-16.1	NT	ND-1.8	238–601	ND-3.3	NT	ND-6.5	
Sufu	*B. subtilis*	2	NT	ND-2.8	NT	NT	13.3–13.4	NT	NT	ND-12.8	Kung, Lee et al. (2007)
Miso	*S. pasteuri*	1	NT	6.4	ND	ND	28.1	NT	ND	NT	Kung, Tsai et al. (2007)
	Bacillus sp.	1	NT	2.7	1.6	2.1	15.3	NT	8.6	NT	
	B. amyloliquefaciens	2	NT	ND-3.1	ND	1.0–2.6	10.4–22.6	NT	ND-8.4	NT	
	B. subtilis	2	NT	ND	ND-1.0	ND-1.2	20.4–39.4	NT	ND-10.0	NT	
	B. megaterium	2	NT	7.4–7.9	ND	ND	12.6–16.5	NT	ND-9.3	NT	
Natto	*B. subtilis*	2	NT	ND-4.7	NT	1.4–1.5	13.4–17.5	NT	NT	NT	Tsai, Chang et al. (2007)
	S. pasteuri	2	NT	ND	NT	1.0–1.2	14.1–15.9	NT	NT	NT	

[a] Quantity of bacterial samples examined.
[b] Trp: tryptamine, Phe: β-phenylethylamine, Put: putrescine, Cad: cadaverine, His: histamine, Tyr: tyramine, Spd: spermidine, Spm: spermine.
[c] NA: Not available.
[d] NT: Not tested.
[e] The range from minimum to maximum. The same number of digits is used after the decimal point in the values, as was presented in the corresponding references.
[f] ND: Not detected.
[g] Mean ± standard deviation. The same number of digits is used after the decimal point in the values, as was presented in the corresponding references.

reduce BA content in fermented soybean foods. To implement appropriate BA control regulations, it is necessary to continuously monitor BA concentrations and establish BA content limits for fermented soybean products. Further research on practical measures to reduce BA content is necessary to ensure the safety of fermented soybean foods.

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Declarations of interest

None.

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