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Review of physiological compounds and health benefits of soybean paste (doenjang): exploring its bioactive components

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Abstract
This review paper explores the history, cultural significance, and functional characteristics of soybean paste (doenjang) in Korean cuisine. In particular, it covers its origins, cultural importance, production methods, functionalities, and associated risks. This review delves into the nutritional and functional aspects of fermented soybean products, focusing on compounds in soybean paste linked to health benefits, such as anticancer, anti-obesity, anti-diabetic, and antithrombotic properties. The key bioactive compounds identified in soybean paste include total phenols, total flavonoids, γ-Aminobutyric acid, vitamin B group, and vitamin E. These compounds are primarily produced through microbial fermentation, which enhances their biological activity. Additionally, the review addresses potential risks such as biogenic amines, aflatoxins, Bacillus cereus contamination, and high sodium levels, and suggests methods for mitigating these risks. By synthesizing current research, this paper aims to provide a comprehensive understanding of the physiological compounds in soybean paste and their health benefits. It also highlights the need for strategies to reduce associated risks.

Keywords Soybean paste, Korean cuisine, Health benefits, Safety profile

Introduction

Fermentation, a crucial process yielding alcohol, organic acids, and CO_2 through the transformative actions of beneficial microorganisms on sugars, is one of the oldest and most integral technologies for food preservation [1, 2]. In particular, in East Asia, where diets predominantly revolve around grains and vegetables, fermented soy-based foods have served as a primary protein source for centuries [3]. In Korea, a rich tradition of fermented foods derived from soybeans—such as fermented soybean paste (doenjang and meju), red pepper paste (gochujang), and soy sauce (ganjang)—has deep historical roots [4].

The Korean Peninsula and Manchuria are recognized as the cradle of soybeans. It is believed that primeval forms of fermented soybean products have been produced since the Bronze Age (around 1500 BC). Soy sauce and soybean paste are estimated to have appeared approximately 200 BC [3, 5]. Soybean paste, an essential ingredient in Korean cuisine, alongside soy sauce, serves as an indispensable flavor enhancer in numerous traditional Korean dishes [4].

Emblematic of Korean ethnic cuisine, soybean paste has seen enduring consumption owing to its robust flavor profile and multifaceted functionalities. The production of soybean paste necessarily involves a fermentation process wherein soybean proteins undergo breakdown and transformation by microorganisms. During fermentation, an array of compounds emerges, shaped by alterations in

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amino acids, lipids, carbohydrates, and other constituents, thereby imparting distinctive traits to soybean paste [6, 7].

The fermentation process yields a variety of biologically active compounds, including isoflavones, polyphenols, flavonoids, daizein, and genistin [8, 9]. In particular, soybean paste is recognized for its diverse health-promoting attributes, demonstrating effectiveness in combating cancer, inflammation, diabetes, oxidation, thrombosis, obesity, and hypertension [10]. The outstanding nutritional and therapeutic properties of soybean paste highlight its significance as a functional food with considerable health benefits.

On the other hand, potential health concerns from excessive soybean paste consumption have been raised. Biogenic amines (BA) formed during fermentation can be toxic, leading to symptoms including breathing issues, headaches, high blood pressure, and irregular heartbeat, especially in cases of amine oxidase deficiency, and potentially causing toxicity [11–14]. Aflatoxin contamination from molds has been reported in some soybean paste samples, and the possibility of the presence of *Bacillus cereus*, a food poisoning pathogen, and high salinity in soybean paste are health concerns [15, 16]. However, chemical, physical, and biological approaches to reduce harmful elements and ensure safer soybean paste consumption have been documented [17–19].

In previous research, the significance of soybean paste as a central element in Korean culinary heritage has been highlighted. This paper meticulously investigated soybean paste, exploring its historical roots, cultural significance, complicated manufacturing methodologies, versatile functionalities, and inherent risks. Understanding these facets of soybean paste is pivotal, particularly given the increasing interest in and consumption of this fermented soybean product. Comprehensive research to unravel its complexities and ensure informed practices in food production and consumption is thus necessary.

History and culture of fermented soybean foods

Documented in ancient records, jang (Korean fermented soybean product) and soy sauce—key ingredients in traditional Korean cuisine—have roots dating back to the Bronze Age. It is speculated that soy sauce and soybean paste were concurrently produced using similar methods during the Three Kingdoms of Korea period [3]. Specifically, referencing historical records from The Chronicles of the Three States during King Sinmun's reign in the 3rd year (AD 683), the inclusion of jang and meju as part of the king's provisions denotes their fundamental role in Korean dietary practices [3, 4]. Korean soy-based condiments such as soy sauce, red pepper paste, and soybean paste are salt-rich. Consequently, they frequently are used as a substitute for salt when seasoning foods [4].

In Korea, crafting fermented soybean products is a crucial year-round affair, marked by dedicated efforts that include scheduling production dates and meticulously documenting management techniques [3]. Traditional fermentation involved a series of processes such as stacking meju in jars, immersion in saltwater and pressing with bamboo sticks to prevent overflow. Moreover, charcoal and red pepper were incorporated into the process, and the jar containing jang was encircled with charcoal, red pepper, and Korean paper, each bearing symbolic significance (Fig. 1). Charcoal and red pepper were combined and introduced into jars to aid in the maturation of the fermented soybean paste, developing its sterilizing and absorption properties [20].

Soybean paste, a contemporary essential food in Korean cuisine, has been recognized and regulated as a traditional food, thereby ensuring quality, processing standards, and packaging [21]. Its acknowledgment in the Codex in 2009 (CODEX STAN 298R-2009) further solidified its global recognition [22]. Thus, soybean paste stands as a distinctive element of Korean food culture, with its consumption persisting through the dedication of both ancestors and descendants. As one of Korea's esteemed culinary legacies, soybean paste has endured across generations, with ongoing endeavors aimed at imparting its significance and value to descendants in the far future.

Manufacturing process of soybean paste

Soybean paste can be categorized into traditional and commercially improved varieties. According to the Food Code of The Ministry of Food and Drug Safety (MFDS), traditional soybean paste typically denotes the sediment separated from fermented meju (utilizing steamed or boiled soybeans as the primary component, which undergo fermentation) in a saline solution. On the other hand, commercially improved soybean paste involves cultivating yeast bacteria using soybeans, rice, barley, wheat, or defatted soybeans as the primary ingredients. This is followed by fermentation and aging, achieved by blending saline into the mixture or fermenting meju in saline, separating the filtrate, and further processing it (Fig. 2) [23].

The distinction between traditional and commercially improved soybean paste lies in their raw materials and the utilization of starters. Traditional soybean paste is manufactured using soybeans as the core ingredient, undergoing a prolonged aging process via naturally fermented paste without the use of starters. In contrast, commercially improved products integrate soybeans as the primary ingredient alongside rice, barley, wheat, or

Fig. 1 Manufacturing process of traditional soybean paste. **A** Traditional form of soybean paste production, **B** Fermentation environment of typical traditional soybean paste, **C** Meju fermenting in jar (A mixture of charcoal, red pepper, meju, and salt water)

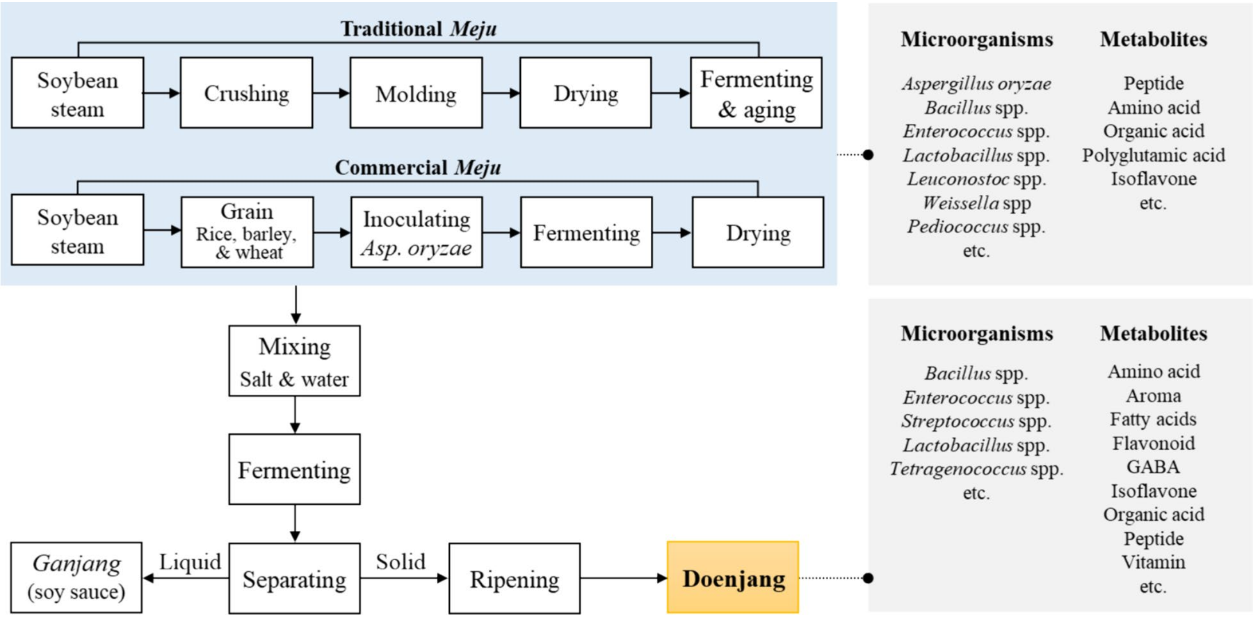

Fig. 2 Soybean Paste Manufacturing Process, Associated Fermentation-Related Microorganisms and Metabolites

defatted soybeans, utilizing starter microorganisms, such as *Aspergillus* spp. and *Bacillus* spp. [3].

It is essential that the starter cultures exhibit enzymatic activity for the degradation of proteins, carbohydrates, and lipids, as this enhances the flavor and productivity of soybean paste. In addition, the microorganisms must be devoid of toxic genes, including those responsible for aflatoxin production, and must not produce *B. cereus* toxins or biogenic amines [3]. These characteristics facilitate standardization and safety control, enabling the production of soybean paste with consistent quality. This approach allows for the hygienic production of fermented soybean products, effectively managing hazardous elements such as pathogenic microorganisms, mycotoxins, and biogenic amines to remain below legal thresholds [3].

Nutritional properties and functionality of soybeans

The primary ingredient of soybean paste, derived from whole soybean (*Glycine max*) seeds, comprises approximately 40% protein, 21% oil, 34% carbohydrates, and 5% other components [24]. Soy protein, rich in glycine and essential amino acids akin to those found in beef or milk, notably boasts a high lysine content. Additionally, soybean fatty acids predominantly consist of unsaturated fats, with linoleic acid and linolenic acid constituting about 60% of total fatty acids. These essential fatty acids exhibit properties that lower cholesterol and improve cardiovascular health [3, 24].

Moreover, soy diet fibers demonstrate significant efficacy in enhancing digestive tract functionality and mitigating cancer risks. In addition, soybeans contain various antioxidants such as polyphenols, flavonoids, tocopherol, and isoflavones, and it has been reported that these antioxidants migrate into soybean paste [25, 26].

Physiologically active substances and health functionality of soybean paste

Soybean pastes exhibit diverse physiological functions through the synthesis of newly formed metabolites during its fermentation, augmenting the inherent attributes of soybeans. Rich in compounds such as polyphenols, flavonoids, vitamin B, and isoflavones, soybean paste has exceptional antioxidant capabilities [9, 27, 28]. Notably, its spectrum of health-enhancing properties includes anticancer, anti-obesity, anti-diabetic, anti-inflammatory, antithrombotic, and anti-hypertensive effects [10].

Physiologically active substances in soybean paste

Polyphenols and flavonoids, renowned for their potent antioxidant properties, play pivotal roles in reducing high blood pressure, preventing cardiovascular diseases, and combating degenerative illnesses [29, 30]. Earlier research has shown that genistein, a key isoflavone compound found in soybeans, exerts anticarcinogenic and anti-proliferative effects, potentially influencing its overall anticarcinogenic properties [30, 31]. Previously, various studies have reported the polyphenols and flavonoids of soybean paste, as shown in Table 1.

Ahn et al. [25] analyzed the total polyphenol content of commercial and traditional doenjang in Korea. The total polyphenol content ranged from 18.71 to 25.47 mg GAE/

Table 1 Total phenol, total flavonoids, glucoside, and aglycone content in soybean paste from previous studies

N[1]	Total phenol	Total flavonoids	Glucoside (mg/kg)			Aglycone (mg/kg)			Refs.
			Daidzin	Genistin	Glycitin	Daidzein	Genistein	Glycitein	
22	18.71–25.47[2] mg GAE[3]/ml	NT[4]	NT	NT	NT	NT	NT	NT	[25]
4	328.26–407.51 mg%	NT	NT	NT	NT	NT	NT	NT	[32]
1	10.9 ± 0.2[5] GAE mg/g	273.2 ± 23.2 μg/g	NT	NT	NT	NT	NT	NT	[33]
2	25.06–29.49 mg GAE/g	NT	NT	NT	NT	NT	NT	NT	[34]
1	301.0 ± 3.1 mg GAE/100 g FW[6]	14.7 ± 0.8 mg CE[7]/100 g FW	NT	NT	NT	NT	NT	NT	[35]
6	928.59–1583.67 mg/kg	NT	34.59–93.15	20.75–56.61	NT	179.78–466.25	51.20–230.69	NT	[36]
1	NT	NT	10.9 ± 0.9	27.2 ± 1.4	2.5 ± 1.0	48.1 ± 3.1	42.5 ± 1.6	11.0 ± 2.8	[8]
7	NT	NT	0.25–12.59	ND[8]-50.67	ND-0.95	220.98–401.37	204.49–380.74	32.94–44.05	[27]
24	NT	NT	NT	NT	NT	86.7–681.8	ND-50.0	NT	[37]

[1] N: Number of samples investigated in the analysis

[2] The range from minimum to maximum

[3] GAE: Gallic acid equivalents

[4] NT: Not tested

[5] Mean ± standard deviation

[6] Fresh weight

[7] Catechin equivalents

[8] ND: Not detected

mL in 22 different doenjang samples, with significant variability observed between regions. The differences in total polyphenol content between regions were attributed to the variety of soybeans used to make meju and the different fermentation times. These factors influence the conversion time of isoflavone glycosides to aglycones, such as genistein and daidzein [25].

Park et al. [26] compared alterations in total polyphenol and total flavonoid contents throughout the fermentation process of soybean products. The total polyphenol content followed this order: soybean (0.585 ± 0.03 mM GAE/mg) < meju (2.310 ± 0.09 mM GAE/mg) < soybean paste (4.17 ± 0.11 mM GAE/mg). Similarly, the total flavonoid content followed the pattern: soybean (1.56 ± 0.117 mg/g) < meju (6.14 ± 0.353 mg/g) < soybean paste (10.68 ± 0.459 mg/g). These results show that the soybean paste undergoing the longest fermentation period exhibited the highest levels of polyphenols and flavonoids.

Moreover, Oh and Kim [38] demonstrated a substantial increase in polyphenol content from soybeans to soybean paste, with the latter exhibiting a content of 28.5 ± 0.3 mg GAE/100 g, approximately five times greater. This increase was notably linked to the fermentation and aging processes. The contents of daidzein and genistein, aglycone isoflavones found in soybean paste, increased with increasing age (1, 3, 5, 7, and 10 years). Specifically, the daidzein and genistein contents in 10-year-old soybean paste were observed to exceed twice the levels found in unfermented soybean paste (daidzein 101.2 ± 1.4 mg/kg and genistein 94.7 ± 3.6 mg/kg versus daidzein 48.1 ± 3.1 mg/kg and genistein 42.5 ± 1.6 mg/kg, respectively) [8].

In addition, several studies have reported that soybean paste contains varying levels of γ-Aminobutyric acid (GABA), vitamin B, and vitamin E (Table 2). GABA, a prominent inhibitory neurotransmitter in the central nervous system, is synthesized from glutamic acid via the action of glutamic acid decarboxylase [39]. Renowned for its diverse physiological roles, GABA exhibits active functions including anti-diabetic, blood pressure modulation, and nerve stabilization effects [40]. Several studies have emphasized the influence of the aging period on soybean paste, demonstrating its capacity to increase GABA levels [8, 41–43].

Jo et al. [8] reported a remarkable 77-fold increase in GABA content in 10-year-old soybean paste (1938.7 mg/kg) compared to its unaged soybean paste (24.9 mg/kg), accompanied by a substantial decrease in the content of precursor glutamic acid. Additionally, Jung et al. [42] identified the peak GABA content at 179 days during the fermentation process of soybean paste, identifying *Lactobacillus* as the dominant cluster. These findings suggested that glutamate decarboxylase activity of *Lactobacillus* sp. facilitated the conversion of glutamic acid to GABA. Consistently, previous studies have highlighted *Lactobacillus* species as primary GABA producers, indicating a likely correlation between increased *Lactobacillus* presence and elevated GABA levels [49, 50].

Table 2 γ-Aminobutyric acid (GABA), vitamin B group, and vitamin E content in soybean paste from previous studies

	N[1]	Content	Refs.
γ-Aminobutyric acid (GABA)	1	24.9 ± 0.8[2] mg/kg	[8]
	1	165 ± 15 mg/kg	[44]
Vitamine B_1 (thiamine)	7	1.837–7.438[3] mg/kg	[28]
Vitamine B_2 (total riboflavin)		1.439–2.118 mg/kg	
Vitamine B_3 (total niacin)		3.929–11.479 mg/kg	
Vitamine B_7 (biotin)	12	4.345–12.544 μg/100 g	[45]
Vitamin B_{12} (cobalmin)	7	0.04–0.50 μg/100 g	[46]
	5	0.04–1.85 μg/100 g	[47]
Vitamin E (tocopherols and tocotrienols)	1	2.40 mg/100 g	[48]

[1] N: Number of samples investigated in the analysis

[2] Mean ± standard deviation

[3] The range from minimum to maximum

The vitamin B group is essential for cell energy metabolism, aiding in energy production, and facilitating the metabolism of carbohydrates, proteins, and fats. Deficiencies in these water-soluble vitamins, including thiamine, riboflavin, niacin, and biotin, can lead to conditions such as beriberi, skin disorders, and growth impairment [51–53]. Soybean paste contains varying amounts of these vitamins, with reported contents of thiamine ranging from 1.837 to 7.438 mg/kg, riboflavin from 1.439 to 2.118 mg/kg, and niacin from 3.929 to 11.479 mg/kg [28]. Even when cooked in soybean paste soup, significant amounts of thiamine, riboflavin, and niacin remain, indicating their potential for easy ingestion post-cooking [54]. The cobalamin content in soybean paste was reported as 0.04–0.50 μg/100 g and 0.04–1.85 μg/100 g in studies by Park et al. [46] and Kwak et al. [47], respectively. Recently, it has been reported that when plant raw materials are fermented, cobalmin is mainly produced by microorganisms [46]. Therefore, the fermentation and aging process of soybean paste revealed the production of significant amounts of functional substances.

Anti-cancer effect

Soybeans are known to contain various anticancer compounds, and their consumption has been associated with a reduced incidence of breast, colon, and prostate cancers. Notably, genistein, an isoflavone present in soybeans, has been demonstrated to inhibit cancer cell proliferation [55]. During the fermentation of soybean-based foods, isoflavones are converted into aglycones, enhancing their bioavailability. Studies indicate elevated levels of genistein and daidzein, predominantly, in fermented soybean products [8, 56].

Investigations of soybean paste have revealed significant inhibition of colon, gastric, lung, and breast cancer cell growth [57–60]. Moreover, Kwon et al. [59] reported an increase in the growth inhibitory effect on cancer cells with prolonged aging of traditional soybean paste. Jo et al. [8] reported a twofold rise in daidzein and genistein levels in 10-year-old soybean paste compared to unfermented soybean paste. In summary, the anticancer efficacy of soybean paste appears to be linked to the presence of genistein. Furthermore, an extended aging period correlates with heightened genistein content in soybean paste, amplifying its potential anticancer properties.

Previously, variations in the anticancer properties of soybean paste have been identified based on distinct fermentation methods and raw materials. Lee et al. [58] reported that the use of onggi (Korean traditional earthenware vessels) during fermentation had synergistic effects on cancer cell growth superior to that of other container types. This outcome is attributed to the enhanced microbial activity facilitated by the air-permeable nature of onggi, which results in more effective fermentation.

Moreover, the anticancer efficacy of soybean paste was found to be influenced by the type of salt utilized [57]. Specifically, soybean paste formulated with sea salt demonstrated notable effectiveness against gastric cancer cells in contrast to paste made with refined salt [61]. Jeong et al. [62] investigated the impact of different salts— refined salt, sea salt, and bamboo salt—on the growth inhibition of colon cancer cells, as well as on apoptosis and the expression of inflammation-related genes during soybean paste fermentation. Their findings revealed a hierarchical order of action in terms of inducing apoptosis and inhibiting inflammation, with soybean paste prepared from refined salt exhibiting lower activity compared to sea salt, followed by bamboo salt, signifying varying degrees of anticancer potential among the different salt types.

Anti-obesity effect

Obesity, a chronic condition on the global rise, is linked to various health complications including hypertension, cardiovascular ailments, heart failure, and nonalcoholic fatty liver disease [63]. Current treatments for obesity include diverse approaches such as anti-obesity medications, bariatric surgery, and fecal microbiota transplantation [64]. Within the domain of obesity management, soybean paste has garnered increased attention for its potential anti-obesity effects.

Studies conducted by Bae et al. [65] and Kwon et al. [66] have demonstrated that mice fed soybean paste experienced reductions in weight gain, blood triglyceride levels, and total cholesterol, confirming its anti-obesity properties. Additionally, an increase in high-density lipoprotein (HDL) cholesterol levels in mice consuming soybean paste was observed, potentially contributing to the prevention of cardiovascular diseases. The anti-obesity impact of soybean paste was attributed to the elevated presence of isoflavones and fermentation byproducts resulting from the fermentation process [66]. Furthermore, the high dietary fiber content of soybeans is known to induce a feeling of satiety, while soybean saponins inhibit fat synthesis, thus aiding in the prevention of obesity. The reduction in total blood cholesterol is attributed to peptides generated through the hydrolysis of soybean protein, which stimulates the excretion of bile acids in the body [65].

Kwak et al. [67] reported that, compared with nonfermented soybean, soybean paste more strongly reduced visceral fat accumulation and adipocyte size in mice. This outcome was attributed to the elevated levels of aglycone isoflavones present in the soybean paste. Most isoflavones in soybeans exist in glycoside form, but during fermentation, microbial β-glucosidase hydrolyzes these into aglycone isoflavones, intensifying their presence in the soybean paste [67]. Clinically, significant reductions in visceral fat and body weight were observed in overweight adults upon regular consumption of soybean paste. Although the exact mechanism involved remains intricate due to the complex composition of soybean paste, the increased presence of isoflavones is speculated to be a contributing factor [68].

Anti-diabetic effect

Oral hypoglycemic agents, commonly used in diabetes treatment often cause side effects such as hypoglycemia induction, diarrhea, weight gain, and blood lactic acid accumulation with prolonged usage. Consequently, recent attention has shifted toward the development of α-glucosidase inhibitors derived from microorganisms, given their potential for mitigating these effects. *Bacillus* spp. are under active research as α-glucosidase inhibitors owing to their rapid growth rate and efficient mass production of metabolites, making them viable candidates for food material applications [69].

Recent studies have actively explored the anti-diabetic effects of soybean paste. Yang et al. [70] observed the anti-diabetic effects of soybean paste in relation to its aging period. Notably, soybean paste aged for less than 10–15 years exhibited particularly heightened α-glucosidase inhibitory activity and hypoglycemic effects. α-Glucosidase, an intestinal epithelial cell enzyme vital for carbohydrate breakdown, facilitates the conversion of disaccharides to monosaccharides. Inhibiting α-glucosidase delays carbohydrate absorption, curbing postprandial blood sugar spikes [71, 72]. Consequently, the consumption of aged soybean paste is presumed to regulate rapid blood sugar elevation after meals.

Moreover, Lee et al. [72] reported that 10 out of 24 soybean paste variants stimulated glucose uptake in muscle cells. Several types of diabetes exhibited glucose uptake levels akin to those of metformin, a commercially available diabetes treatment. This effect is attributed to daidzein and genistein, which are aglycone forms, potentially improving insulin resistance. However, further investigations are warranted to elucidate the precise mechanisms underlying this phenomenon.

Thrombolytic effect

Blood clots form in blood vessels or tissues following damage to blood vessels, stemming from the clotting process. Fibrin clots specifically arise from the conversion of fibrinogen, a plasma protein, into fibrin, catalyzed by activated thrombin. These fibrin clots are broken down by fibrinolytic enzymes. When the thrombolytic mechanism encounters issues, it can lead to thrombosis [73]. If thrombosis persists without proper breakdown, it can result in diseases, such as cerebrovascular disease and myocardial infarction [74].

However, conventional thrombosis treatments often exhibit limited activity and high cost and are primarily administered intravenously, presenting a challenge for oral administration [75]. Consequently, there is a growing need to explore natural products or microbial sources for substances that exhibit potent thrombolytic activity. Microbial enzymes have garnered attention for their high specificity and potential for mass production via fermentation, offering prospects for industrial-scale application [76].

Among the microorganisms isolated from traditional Korean soybean fermentation foods, *Bacillus* strains have shown a close association with thrombolytic activity. Kim et al. [76] revealed a positive correlation between the thrombolytic activity of soybean-based products, including meju and *koji*, and the density of *Bacillus*. Additionally, Kim et al. [77] reported thrombolytic activity in various *Bacillus* species isolated from traditional soybean paste, with *Bacillus subtilis* demonstrating the highest activity among the strains tested.

Lee et al. [78] conducted research that highlighted the thrombolytic activity of *Bacillus* strains isolated from fermented soybean products (doenjang, cheonggukjang, and meju). *Bacillus amyloliquefaciens* HCD2 demonstrated remarkable thrombolytic efficacy. Utilizing the HCD2 strain in conjunction with other functional strains in fermented soybean foods holds promise for augmenting both the functionality and safety of the resultant fermented product. Yi et al. [79] isolated yeasts from fermented foods, including those found in soybean paste, which exhibited remarkable thrombolytic activity. Notably, the *Saccharomycetales* sp. AFY-1 strain isolated from soybean paste exhibited thrombolytic activity approximately 1.75 times greater than that of the control group, plasmin.

In summary, diverse microorganisms found in fermented foods such as soybean paste can generate thrombolysis-related enzymes. Further exploration, including safety validation for strains exhibiting outstanding thrombolysis, is anticipated to pave the way for their utilization as starters in fermented food production. Microorganisms with verified safety profiles are significantly advantageous because they can be directly consumed as food. This advantage is poised to boost the consumption of fermented foods and foster their evolution into high-value businesses.

Hazardousness and solutions of soybean paste

Biogenic amine content and reduction measures in soybean paste

The production of BA primarily occurs through the decarboxylation of amino acids during the fermentation, ripening, or spoilage of protein-rich foods [80]. Excess amounts of histamine and tyramine can lead to symptoms such as headaches, hives, diarrhea, high blood pressure, and bleeding when consumed excessively [12, 13].

Soybean paste, which is rich in protein, has varying BA levels. Some traditional doenjang products have concentrations of BA exceeding 200 mg/kg [81–83]. However, research on commercial soybean paste revealed histamine and tyramine levels within or below 150 mg/kg in several studies [44, 84–86]. No specific regulations exist for BA in doenjang. However, a recommended limit for histamine has been established at 500 mg/kg [3]. Importantly, biogenic amines are usually detoxified through monoamine oxidase (MAO) and diamine oxidase (DAO) in the small intestine [11, 12].

The use of standardized starter cultures can effectively reduce BA production by limiting microbial contamination and decarboxylase activity. Employing *Bacillus* strains that produce bacteriocins and degrade BAs represents a promising approach for enhancing the safety of soybean paste fermentation processes [87–90]. Incorporating these strains into fermentation processes or as supplements shows potential for mitigating the toxicity risk associated with BA accumulation.

Aflatoxin content and reduction measures in soybean paste

Aflatoxin, a mycotoxin with known carcinogenic, mutagenic, and hepatotoxic effects, poses significant health hazards, including intestinal and kidney bleeding, in most animal species. The Korea Food and Drug Administration (KFDA) limits total aflatoxins (B1, B2, G1, and G2) to 15.0 µg/kg and aflatoxin B1 to 10.0 µg/kg in soybean paste [23].

In particular, the potential for aflatoxin contamination by *Aspergillus flavus* has been noted during traditional natural fermentation processes. However, research has demonstrated that even if aflatoxins are produced, they can be degraded by various factors during the fermentation process. Ammonia and browning products from fermentation, an increase in pH, sunlight, and especially the addition of charcoal, have been shown to degrade the formed aflatoxins during the process [91].

Additionally, chemical, physical, and biological methods have been developed for the degradation of aflatoxins. Among these, biological methods have emerged as a promising approach due to their efficacy and the maintenance of food properties [17, 92–94]. Specifically, employing specific starter strains for fermented foods has shown promise in effectively mitigating mycotoxin contamination risks in final products [15, 95, 96].

The previous research indicates that *B. subtilis*, a key fermenting microorganism, inhibits mold growth and aflatoxin production [97]. Inoculating soybean paste with *B. subtilis* and other beneficial bacteria significantly reduced aflatoxin B1 levels (21.6%-70.4%), demonstrating its effectiveness in ensuring soybean paste safety.

Bacillus cereus contamination and reduction measures in soybean paste

B. cereus, predominantly found in soil, poses a significant risk of food contamination due to its ability to form endospores and biofilms, allowing it to survive in various food production and packaging environments [98]. Regulatory guidelines by the KFDA stipulate that *B. cereus* levels in soybean paste should remain below $< 10^4$ cfu/g [23]. Studies have identified *B. cereus* in several soybean paste samples, some with potential for biogenic amine production and toxin genes [87, 94, 99, 100].

Numerous studies have explored *B. cereus* reduction methods in soybean paste. Traditional high-temperature heat treatments, while effective, risk altering the color and flavor profiles inherent to soybean paste. To mitigate potential alterations in color or flavor, commonly induced by prolonged high-temperature heat treatment in foods like soybean paste, a series of complex treatments (such as joule heating, ultra-high pressure, grapefruit seed extract, and EDTA) were employed instead of singular methods. This approach aimed to minimize alterations in the physical properties of food while enhancing microorganism reduction efficiency [18, 19].

Kim et al. [101] identified a strain with remarkable inhibitory effects on *B. cereus* found in the fermented soybean microbiota, suggesting its potential as an effective suppressor when used as a starter culture. Hence, a paramount strategy involves designing hygienic practices throughout raw material cultivation, processing, and manufacturing processes to minimize *B. cereus* contamination [98].

High sodium content of soybean paste

Salt is the main ingredient that affects the fermentation of soybean paste and affects its taste and quality. In particular, salt selectively causes fermented microorganisms to grow in fermented foods and inhibits the proliferation of various bacteria [102]. The presence of high salinity in soybean paste has been demonstrated to prevent the growth of toxin-producing fungi and aflatoxins [103]. Studies have demonstrated that mold growth is inhibited at 15% and 18% salinity, and BAs were hardly detected in the 18% salt soybean paste [104].

There is also concern that the high salt content of soybean paste deteriorates health. However, Mun et al. [105] performed an in vivo study reported that eating soybean paste was not a direct cause of high blood pressure and that eating soybean paste improved blood pressure in normal and healthy individuals. O'Donnell et al. [106] suggest an absence of conclusive evidence supporting the link between reduced sodium intake and decrease cardiovascular disease incidence.

Despite the common association of salt with obesity, recent studies have presented contrasting evidence. For instance, previous research demonstrated that increase sodium intake among mice on a high-fat diet resulted in weight reduction [107]. In particular, Jung et al. [108] confirmed that the consumption a balanced Korean diet, incorporating fermented soybean products, reduction metabolic diseases such as hypertension, diabetes, and obesity.

Conclusion

The investigation of soybean paste in this comprehensive review sheds light on its multifaceted nature within Korean culinary heritage. By exploring its historical significance, cultural associations, and intricate production methods, this paper provides a holistic perspective essential for understanding its role in both traditional and contemporary diets. The focus on nutritional and functional aspects underscores the richness of soybean paste, highlighting its compounds associated with health benefits, such as anticancer, anti-obesity, anti-diabetic, and antithrombotic effects. To enhance these health benefits, advanced soybean pastes incorporate starter cultures that improve flavor and productivity while ensuring safety. This is achieved by selecting starter cultures that eliminate toxic genes such as aflatoxins and prevent the production of *B. cereus* toxins and biogenic amines. Above all, it is of the utmost importance for responsible organizations such as the Korea Food and Drug Administration (KFDA) and the producers themselves to conduct rigorous monitoring of hygiene standards at production facilities and to implement a continuous evaluation process to ensure the absence of harmful substances in commercially available soybean paste products.

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