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REVIEW ARTICLE
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A Summary Review of Biogenic Amines in Southeast Asia Fermented Food, the Factors and the Reduction Methods

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ABSTRACT

Southeast Asia boasts a rich variety of food, mainly featuring fishery and fermented products. This region is home to a wide range of indigenous foods, each unique to its own country. Most of these culinary offerings consist of meat and seafood. Various food items subjected to testing were found to contain a spectrum of biogenic amine compounds such as tryptamine, putrescine, cadaverine, histamine, spermine, spermidine, and tyramine, with histamine being the most frequently analyzed. Most food samples tested complied with the maximum biogenic amine content standards. Biogenic amines (BA) are organic compounds with one or more amine functional groups (-NH2) formed during microbial fermentation. Consuming foods high in BA is linked to adverse health effects like migraines, high blood pressure, and tachycardia. BA toxicity can occur at levels much lower than the regulatory and suggested toxic doses, influenced by an individual's sensitivity, alcohol consumption, and certain medications. Although BA are found in many fermented foods, food safety and public health professionals often lack awareness of the potential health risks and control strategies. This review examines the presence of BA in Southeast Asian foods, identifies contributing factors and formation mechanisms, and explores potential strategies for reducing their levels.

Keywords: Biogenic amine, Food safety, Indigenous food, Southeast Asia

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INTRODUCTION

Southeast Asia has diverse and vibrant food culture, which is influenced by indigenous traditions such as, Chinese, Indian, and European cultures (Putra et al., 2023). Furthermore, Southeast Asia is a maritime region and has been one of the top producers of fish and fishery product such as fermented fish product (Tint et al., 2020; Narzary et al., 2021). Apart from the wealth of natural resources, the diversity of food products is also achieved as a result of various food processing techniques such as smoked and fermentation. Aside from natural resource wealth, the diversity of food products is also achieved through various food processing techniques such as smoking and fermentation. Food diversity can imply the diversity of compounds contained in food. For example, fermented food is food produced through microbial activity, where the growth of microorganisms or microbial activity is controlled (Dimidi et al., 2019). This process generates enzymes that convert food components. However, not all compounds in food are safe to eat in certain amounts; biogenic amines are one of the compounds that can be found naturally or formed as a result of food processing, which can cause harm in certain amounts.

Biogenic amines are organic compounds that contain one or more amine functional groups (-NH2). It consists of a lot of types such as histamine, spermidine, spermine, cadaverine, putrescine, etc. Most Asian fermented food mainly fermented soybean food contain potentially hazardous biogenic amine levels (Park et al., 2019). Biogenic amine compounds can be found naturally in foods such as vegetables, fish, fruits, meat, and wine (Ruiz-Capillas & Herrero, 2019). Moreover, biogenic amine can also produce by decarboxylation of amino acids by enzyme from microorganism that emerged or added during fermentation process or due to uncontrolled

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fermentation (Moniente et al., 2022). Some bacteria that causing formation of biogenic amine is *Enterobacteriaceae* which can be found in the fermented fish production, *Staphylococcus* and *Tetragenococcus* which can be found in Korean traditional soy sauce (Kim et al., 2021; Meng et al., 2022). Lactic acid bacteria (LAB) are typically identified as the primary producers of BA in fermented foods, which causes mild to serious health problem such as headache, heart palpitations, vomiting, etc. if the compounds reach the threshold level (Barbieri et al., 2019). Determining the exact toxicity threshold for BA is challenging because the toxic dose is highly dependent on the effectiveness of individual detoxification mechanisms, which can vary. This variation is influenced by individual sensitivity, alcohol consumption, and the intake of drugs that either inhibit monoamine oxidase or interact with the amine oxidase enzymatic pathways responsible for detoxifying excess BA. When the capacity of these amine-metabolizing enzymes is exceeded or specific inhibitors interfere with their activity, vasoactive BA such as histamine, tyramine, and phenylethylamine, can lead to food intoxication.

Establishing toxicological thresholds for BA is difficult because the severity of toxic effects differs among individuals, depending on their sensitivity and the presence of other amines in foods. The toxicological threshold can range from a few mg/kg in sensitive individuals to several hundred mg/kg in a healthy person. A total BA level of around 1000mg/kg in food has been reported as potentially hazardous. Several regulatory organizations such as Health Canada, US FDA, EFSA, Food and Agriculture Organization/World Health Organization (FAO/WHO), have established legal maximum limits for histamine levels in fish and fermented fish products to ensure safe consumption. Despite the toxicological risks associated with high levels of BA in food, these organizations have not set specific regulations for BA content in food, except for histamine in fish and fish products. The significance of this issue has prompted government intervention to establish regulations concerning the threshold levels of biogenic amines, notably focusing on certain types such as histamine. Generally, the threshold of histamine level is decided based on the type of food product, and in each country is difference, for example the limits of Histamine for enzyme-treated products (fermented) in Indonesia and Morocco are 100ppm, in People's Republic of China and Taiwan (ROC) are 400ppm and for ESFA (The European Food Safety Authority) and Canada are 200ppm (DeBeeR et al., 2021). Table 1 summarizes the regulatory thresholds for BA in various countries and regulatory agencies. Health Canada regulates histamine levels in anchovies, fermented fish sauces, and pastes, while the US FDA has set a guidance level for histamine in fish. European Commission, FAO/WHO and Codex have established limits for histamine in different fish and fish products. Several other countries, including Australia, New Zealand, Turkey, Korea, Finland, Switzerland and the Slovak Republic have specific regulatory limits for histamine in fish and/or seafood. Additionally, the Slovak Republic has set an upper limit for tyramine in cheese (Turna et al., 2024).

However, the wide diversity of biogenic amines poses a challenge, as current regulations are limited in scope and unable to encompass the full spectrum due to insufficient research on these compounds and its documented health risk. Therefore, the purpose of this review is to evaluate the likelihood of the presence of BA in South East Asians foods, identify the factors contributing to their formation, and explore potential strategies for mitigating their levels.

Biogenic Amine Contents in Indonesian Food

Indonesia was one of the leading producers of fisheries in Southeast Asia, with significant annual production. Consequently, a wide variety of fish products, both fresh and processed, circulated in the market. Biogenic amines were naturally present in fish products. The biogenic amine content in Indonesian foods was shown in Table 2. This was demonstrated by the research of Yusni et al. (2019), which found that Tuna fish (*Thunnus* sp.) from Belawan, North Sumatra, Indonesia, contained histamine levels of 2.5-13mg/L from fresh conditions to 4 weeks of storage. Skipjack tuna (*Katsuwonus pelamis*) in Banda Aceh contained histamine levels of 0-3.9ppm, and the histamine content was successfully controlled by providing special cooling treatment for the fish

Table 1: Countries with thresholds established for biogenic amines

Biogenic amine	Threshold	Country of Agency	Food product
Histamine	400mg/kg	EFSA FAO/WHO	Fermented fish sauces
	200mg/kg	Canada	Anchovies, fermented fish sauces and pastes
	200mg/kg	FAO/WHO Codex Alimentarius Australia New Zealand Turkey Korea Slovak Republic	Fish and fish product
	100mg/kg	Canada Finland Switzerland	Fish and fish product
	200mg/kg–400mg/kg	EFSA	Salted fish of Scombridae, Clupeidae, Engraulidae, Coryfenidae, Pomatomidae, Scombresosidae origin
	100mg/kg–200mg/kg	EFSA	Scombridae, Clupeidae, Engraulidae, Coryfenidae, Pomatomidae, Scombresosidae origin
	50mg/kg	USA	Edible fish
Tyramine	200mg/kg	Slovak Republic	Cheese

Source: Turna et al. (2024).

Table 2: Biogenic amine contents in Indonesian food

Food Products	BAs Found					References
	Tryptamine	Putrescine	Cadaverine	Histamine	Tyramine	
Terasi	417mg/100g	2542mg/10g	1796mg/10g	183mg/100g	1329mg/10g	Ambarita et al. (2020)
Tuna Fish				2.5-13mg/L		Yusni et al. (2019)
Cakalang Fish				0-3.9ppm		Mawaddah et al. (2023)
Tongkol Abu Fish				56-95ppm		Witria & Zainuri (2021)
Komu Fish				28mg/100 g		Hattu et al. (2016)

(Mawaddah et al., 2023). Mackerel fish sold in Madura was found to contain histamine levels of 56-95ppm (Witria & Zainuri, 2021). Another fish, Komu fish, commonly found in Indonesian waters, contained histamine levels of 28mg/100g (Hattu et al., 2016). Not only fresh fish products, but other fishery products such as fermented shrimp paste were also detected to contain BA. In shrimp paste and fish from 12 provinces in Indonesia, tryptamine content was found to be 417mg/100g, putrescine 2542mg/100g, cadaverine 1796mg/100g, histamine 183mg/100g, and tyramine 1329mg/100g (Ambarita et al., 2020). Shrimp paste was typically produced on a small industrial scale with a fairly long fermentation period, making its quality easily influenced by natural and environmental factors such as temperature, workers, and surrounding microbes. Additionally, the abundant amino acid content in shrimp also facilitated the formation of biogenic amines under suitable conditions (Yu et al., 2022; Li et al., 2023). Fermentation products found in Indonesia generally underwent traditional fermentation processes that tended to be less controlled, leading to contamination and the escalation of biogenic amine compounds. Unfavorable levels of BA, additionally, when handling, improper processing techniques and cross contamination as well as shrimp shrimp, bacterial populations may grow, further contributing to BA levels. Furthermore, as mentioned in earlier research, the environment and equipment used in processing plants belong to small scale enterprises may contaminate with bacteria that produce HIS. Several factors influence these changes, including the type and quantity of microflora, chemical and physical characteristics, hygienic processing methods, availability of precursors, amount of meat used, types of ingredients added, and the quality of the raw material. Food is the main source of amino-positive bacteria, which play a crucial role in the formation of BAs (Aladhadh et al., 2024).

Biogenic Amine Contents in Thailand Food

The diversity of research, particularly on BA content in Thailand, was mostly focused on non-fish products. The biogenic amine content in Thailand foods was shown in Table 3. Nham, a fermented pork product with a unique texture and savory taste, was one such example (Visessanguan et al., 2006). Pork was fermented for approximately three to five days before consumption. In a study by Santiyanont et al. (2019), it was found that Nham contained various biogenic amines such as putrescine, cadaverine, histamine, tyramine, spermidine, and spermine. Thailand was also renowned for its diverse range of sauces. Muangthai & Nakthong (2014) investigated the histamine levels in various sauces, including soy sauce and sweet soy sauce (17.76-25.33mg/kg), oyster sauce (similar histamine content to fish sauce: 7.5-15.11mg/kg), and mushroom sauce (lowest histamine content: 8.02-8.11mg/kg). In another study by Deetae et al. (2017), it was reported that soy sauce and soybean paste contained tryptamine, phenylalanine, putrescine, cadaverine, histamine, tyramine, and spermidine. The total biogenic amine content in soy sauce ranged from 61.85 to 99.18ppm, while in soybean paste, it was 19.23ppm. Histamine and tyramine were the highest biogenic amine contents observed. Apart from meat and sauces, research had also been conducted on traditional Thai herbs or plants such as *Caesalpinia sappan* L., *Kaempferia parviflora*, *Berchemia floribunda* Wall, *Prunus cerasoides* D.Don, and *Piper ribesioides* Wall. Muangthai et al. (2017) reported that these common Thai plants contain histamine and tyramine in the range of 0.36-6.33mg/100g and up to 1.32-17.59mg/100g, respectively. The total biogenic amine content varies with the use of extraction method. Organic solvents such as ethanol tend to increase the histamine levels while the use of hot water does the opposite by increasing the tyramine levels.

Biogenic Amine Contents in Cambodia Food

Fisheries play a vital role in generating income for the Cambodian community. Therefore, various technologies are essential for preserving fish, including smoking and fermentation. The biogenic amine content in Cambodia foods was shown in Table 4. In a study by Douny et al. (2021), it was discovered that out of 9 fish species in Cambodia subjected to smoking, they contained various biogenic amines, namely methylamine, tryptamine, 2-phenylethylamine, putrescine, cadaverine, histamine, serotonin, tyramine, spermidine, and spermine ranging from 4.5mg/kg up to 1172mg/kg. Choeng et al. (2023) analyzed the histamine levels in fermented fish products in Cambodia, such as Nem trey, Sangvak (minced fish), and Nem sbek chrouk (minced fish mixed with pork skin). Fermented fish products from the Battambang and Kratie provinces had histamine levels ranging from 0 to 156.43mg/kg. Besides fermented seafood products, Cambodia also employs fermentation processes on vegetables. Ly et al. (2020) tested various fermented fishery product yang ternyata mengandung putrescine (48-386ppm), cadaverine (0-788ppm), histamine (0-422ppm), and tyramine (0-299ppm), with the highest levels found in fermented fish products also tested fermented vegetables, which contain putrescine (15-119ppm), cadaverine (0-68ppm), histamine (0-66ppm), and tyramine (0-53ppm). Among them, mustard and papaya fermentation products exhibited the most comprehensive biogenic amine content. Cambodia has several traditional food products that contain relatively high levels of biogenic amines due to the fermentation process.

Table 3: Biogenic amine contents in Thailand food

Food Products	BAs Found								References
	Tryptamine	Putrescine	Phenylalanine	Cadaverine	Histamine	Spermine	Spermidine	Tyramine	
Nham		14.29-531.06mg/kg		6.36-170.86mg/kg	4.65-45.21mg/100g	15.76-26.02mg/kg	0-6.54mg/kg	21.75-384.9mg/100g	Santiyanont et al. (2019)
Soy sauce and sweet soy sauce					17.76-25.33mg/kg				Muangthai & Nakthong (2014)
Fish and oyster sauce					7.5-15.11mg/kg				
Mushrooms sauce					8.02-8.11mg/kg				
Soy Sauce	3.8ppm	16.76-22.99ppm	3.7-5.99ppm	0.98-3.44ppm	19.06-42.97ppm		2.26-3.99ppm	26.78-31.01ppm	Deetae et al. (2017)
Soybean paste	1.17ppm	1.25ppm	0.25ppm	3.49ppm	4.14ppm		3.97ppm	5.81ppm	
Caesalpinia sappan L.					2.44-6.33mg/100g			15.38-17.59mg/100g	Muangthai et al. (2017)
Kaempferia parviflora					1.36-3.52mg/100g			16.05-117.43mg/100g	
Berchemia floribunda Wall					0.38-1mg/100g			1.58-2.21mg/100g	
Prunus cerasoides D.Don					0.36-1.73mg/100g			1.32-1.47mg/100g	
Piper ribesioides Wall.					0.70-0.95mg/100g			2.21-4.45mg/100g	

Table 4: Biogenic amine contents in Cambodia food

Food Products	BAs Found							References
	Tryptamine	Putrescine	Cadaverine	Histamine	Spermine	Spermidine	Tyramine	
Fermented Fish : Nem trey, Sangvak, Nem sbek chrouk				0-156. 43mg/kg				Choeng et al. (2023)
Prahok and toeuk-trey	17.94-139.65ppm	9.94-558.38ppm	9.22-540.82ppm	5.04-368.58ppm			0.96-124.98ppm	Sokvibol et al. (2022)
Teuktrey		233ppm	368ppm	155ppm			144ppm	Ly et al. (2020)
Prahok		360ppm	522 ppm	179ppm			218ppm	
Kapi		112ppm	ND-270	ND-46			ND-57	
Paork chav		386ppm	672ppm	422ppm			299ppm	
Paork chouk		49ppm	43ppm	260ppm			ND-82	
Mam trey		378ppm	930ppm	320ppm			ND-196	
Trey proheum		153ppm	297ppm	ND-183			79ppm	
Chaaipov brey		15ppm	ND-12	ND			ND	
Chaipov paem		14ppm	ND-10	ND			ND	
Trasork chav		70ppm	ND-23	ND-18			15ppm	
Spey chrourk		95ppm	29ppm	66ppm			44ppm	
Mam lahong		119ppm	68ppm	49ppm			53ppm	
Smoked freshwater fish	<1.7-21.4mg/kg	<4.4-64mg/kg	<1-172mg/kg	<11.1-24.2mg/kg	6.5-62.4mg/kg	7.8-82.9mg/kg	<0.8-38.4mg/kg	Douny et al. (2021)

Biogenic Amine Contents in Malaysian Food

The presence of biogenic amine compounds has been a matter of concern in Malaysia. The biogenic amine content in Malaysian foods was shown in Table 5. In a study by Saaid et al. (2009), testing was conducted on the biogenic amine content in various types of food sold in several supermarkets in Penang, Kelantan, and Melaka. Some of these foods included canned fish, salted fish, budu or fermented fish sauce, cincalok (shrimp sauce), meat, canned fruits or vegetables, juices, and soy products. Fish sauce and shrimp sauce were found to have the highest biogenic amine content compared to other types of food. Yue et al. (2023) also analyzed the biogenic amine content in samples of fresh chicken, beef, and mutton. Based on the results obtained, it was found that the average biogenic amine content in all three types of meat was tryptamine (17.5mg/kg), phenylethylamine (12.4mg/kg), putrescine (20.6mg/kg), cadaverine (13.4mg/kg), histamine (17.1mg/kg), tyramine (9.3mg/kg), and spermidine (11.3mg/kg). The content of biogenic amine compounds was found to be higher in chicken meat, followed by goat meat, and lastly beef. In addition to the types of food mentioned, there was also testing conducted on the biogenic amine content in traditional wines. Research conducted by Yue et al. (2021) analyzed the biogenic amine content in traditional Malaysian wines such as Toddy, Mijiu, Uangjiu, and Huangjiu produced in Kuala Lumpur, Perak, Penang, Johor, and Sarawak. The results showed that on average, the four types of Malaysian wine beverages contained biogenic amines such as tryptamine (10.3mg/L), phenylethylamine (1.4mg/L), histamine (16.8 mg/L), putrescine (3.4mg/L), cadaverine (28.5mg/L), tyramine (0.6mg/L), and spermidine (6.5mg/L).

Biogenic Amine Factors

As previously explained, biogenic amines were compounds naturally found in fresh foods and formed due to food processing. The presence or formation of biogenic amines could be influenced by internal and external factors of the food. The internal factors of food included:

1. Amino Acid Content in Food

Proteins and/or amino acids were precursors of biogenic amines; therefore, the amino acid content in food correlated with the biogenic amine content in the food (Visciano & Schirone, 2022). High levels of amino acids in food could allow for an increase in biogenic amine levels in the food (Dabadé et al., 2021). For example, certain fish species such as tuna, mackerel, and sardines had higher levels of free histidine, leading to a higher probability of containing histamine (Peivasteh-Roudsari et al., 2020). Additionally, in fruits and vegetables, the ripening process

Table 5: Biogenic amine contents in Malaysian food

Food Products	BAs Found							References
	Tryptamine	Putrescine	Cadaverine	Histamine	Spermine	Spermidine	Tyramine	
Budu	82.7mg/kg	38.1mg/kg		187.7mg/kg		5.1mg/kg	174.7mg/kg	Ruby et al. (2023)
Belacan	ND	137 mg/kg	50.1 mg/kg	57.6 mg/kg			8.64mg/kg	
Cincalok	ND	330.7mg/kg		126.1mg/kg		ND	448.9mg/kg	Saaid et al. (2009)
Canned fish	18.2mg/kg	12.3mg/kg		3.2mg/kg		2mg/kg	11.8mg/kg	
Salt-cured fish	ND	101.4mg/kg		27.9mg/kg		7.6mg/kg	63.2mg/kg	
Beef salami	3.0mg/kg	ND		3.9mg/kg		ND	1mg/kg	
Frozen minced beef	ND	1.5mg/kg		1.8mg/kg		1.4mg/kg	1.2mg/kg	
Beef green peppercorn	ND	ND		ND		0.8mg/kg	ND	
Beef burger	1.3mg/kg	ND		ND		ND	8.5mg/kg	
Prune in brine	6.2mg/kg	1.2mg/kg		ND		ND	ND	
Sour ginger	ND	6.5mg/kg		ND		2mg/kg	ND	
Pickled leeks	ND	3mg/kg		ND		ND	ND	
Salted plum	12.0mg/kg	ND		ND		ND	ND	
Tomato puree/	ND	1.7mg/kg		ND		2.4mg/kg	ND	
Tomato ketchup	ND	3.6mg/kg		ND		3.4mg/kg	ND	
Tempe	15.6mg/kg	116.9mg/kg		4.1mg/kg		11.6mg/kg	4.3mg/kg	
Soy bean sauce	ND	1mg/kg		9.6mg/kg		ND	1mg/kg	
Salty soy sauce	ND	ND		2mg/kg		ND	ND	
Taucu (salty bean)	ND	59.0mg/kg		0.8mg/kg		ND	ND	
Soya bean milk	20.2mg/kg	ND		17.5mg/kg		1.3mg/kg	1.7mg/kg	
Toddy Coconut wine	ND	ND	104mg/L	38.1mg/L		ND	2.4mg/L	Yue et al. (2021)
Mijiu rice wine	17.4mg/L	9.9mg/L	1.7mg/L	10.5mg/L		6mg/L	ND	
Uangjiu red wine	14.9mg/L	2.4mg/L	5.9mg/L	8.6mg/L		5.6mg/L	ND	
Huangjiu yellow liquor	8.7mg/L	1.1mg/L	2.2mg/L	10.1mg/L		14.4mg/L	ND	
Fresh chicken	21.9mg/kg	28.3mg/kg	12.8mg/kg	23.2mg/kg		16.3mg/kg	5.6mg/kg	Yue et al. (2023)
Fresh beef	8.6mg/kg	7.2mg/kg	23.9mg/kg	17.8mg/kg		17.6mg/kg	16.9mg/kg	
Fresh mutton	21.9mg/kg	26.4mg/kg	14.2mg/kg	10.4mg/kg		<LOD	5.5mg/kg	

could increase the levels of free amino acids, resulting in the formation of biogenic amines, such as the increase in putrescine levels during the ripening of bananas (Borges et al., 2019; Borges et al., 2020).

2. Endogenous Enzyme Content

Endogenous enzymes were naturally present in food within tissues or cells, which could cause desired or undesired effects. These enzymes could alter the properties of post-harvest products and modify cell tissues of both plants and animals, changing their texture, color, aroma, and nutritional value (Motta et al., 2023). Some fresh foods contained endogenous decarboxylase enzymes capable of converting amino acids into biogenic amines, remaining active during post-harvest or storage, leading to high levels of biogenic amines. For example, during the freezing of meat, cadaverine and putrescine could still form due to endogenous decarboxylase enzymes released from muscle cell damage during freezing or thawing, especially at -18°C (Motaghifar et al., 2021). BAs in foods are mainly synthesized by the bacterial action by decarboxylation of certain amino acids involving substrate specific decarboxylase enzymes. For example, Histidine is decarboxylated to form histamine by histidine decarboxylase; Lysine is converted to cadaverine by lysine decarboxylase. Also, deprenyl is produced from tyrosine and phenylalanine by tyrosine decarboxylase to form tyramine and phenylethylamine, respectively. Putrescine can be formed through two pathways: they include the conversion of ornithine to putrescine by ornithine decarboxylase and the deamination of agmatine. Spermine and spermidine are the polyamines obtained from putrescine. The agmatine system involves three enzymes: cluding agmatine deiminase, putrescine carbamoyltransferase, and carbamate kinase (Doeun et al., 2017).

3. Natural Microbial Content in Food

Fresh foods sometimes contained natural microbiota strains capable of producing biogenic amines. In fish, the types and amounts of microorganisms depended on the fish's habitat conditions (Visciano et al., 2012). The formation of biogenic amines in fish was temperature-dependent; at optimal temperatures, histidine decarboxylating bacteria naturally present in the gut, gills, and skin of freshly caught fish could multiply rapidly and produce histamine more quickly (AE Refai et al., 2020).

The external factors that could influence biogenic amine levels in food included:

1. Microbial Activity

Microorganisms, including bacteria, yeasts, and molds, could produce biogenic amines through decarboxylation activity (Ahmad et al., 2019). Thus, the presence of these microorganisms, whether intentionally added, such as during fermentation, or due to contamination, could promote the formation of biogenic amines in food (Mahmoudzadeh et al., 2022). Fermentation bacteria, such as lactic acid bacteria, have genes that code for decarboxylase enzymes. Under temperature and pH conditions suitable for microbial growth during fermentation, this facilitates rapid multiplication of fermentation bacteria and a concurrent increase in decarboxylase enzyme activity (Visciano & Schirone, 2022).

2. Hygiene and Sanitation

Poor cleanliness and sanitation during food handling could facilitate the proliferation of microbes that form biogenic amines (Mohamed et al., 2024). Additionally, cross-contamination and inadequate equipment cleaning could increase biogenic amine content (Ekici & Omer, 2020; Jančová et al., 2020). Food can become contaminated with various types of spoilage microbes and pathogens due to inadequate hygiene and sanitation practices. This group of microbes is capable of producing various BAs. The greater the diversity of microbial groups present, the greater the diversity of biogenic amine-producing contaminants (Benkerroum, 2016).

3. Handling and Storage Conditions

After harvest, fresh foods underwent protein breakdown into amino acids, which could then convert into biogenic amines through endogenous or microbial decarboxylases (Durak-Dados et al., 2020). Fresh foods, especially fresh fish, needed to be stored at cold and nearly frozen temperatures to maintain freshness and prevent the growth of contaminant microbes (Jaguey-Hernández et al., 2021). Improper handling and storage, such as delays in cooling or exposure to insufficiently cold temperatures, could facilitate the growth and activity of biogenic amine-producing bacteria (Ruiz-Capillas & Herrero, 2019). Histamine and other BAs can form during storage if not handled properly. BAs can be formed from the decarboxylation of amino acids by enzymes from microbes associated with fresh seafood (Oktariani et al., 2022).

4. Additives and Preservatives

Additives and preservatives such as sulfites, nitrites, and certain spices had antimicrobial properties (Lee & Paik, 2016). Their use in food could inhibit the growth of biogenic amine-producing bacteria (El-Mossalami et al., 2011; Doeun et al., 2017). Nitrites can inhibit microbial growth by disrupting their respiratory system. Therefore, nitrites in food products can prevent the accumulation of histamine, putrescine, and cadaverine (Cunningham-Bussel et al., 2013; Omer et al., 2021). Spices contain spicy ingredients, organic acids, antioxidants, and act as antiseptics that can inactivate the pathogenic and spoilage organism. Spice extracts prevent BA formation in food by slowing down the growth of BA-positive bacteria found in meat products. These bacteria can increase the production of biogenic amines like tyramine, putrescine, cadaverine, and histamine. The antimicrobial effects of spice extracts come from the combined action of their specific compounds working together (Sun et al., 2018). Therefore, their presence was one of the factors influencing BA content in food.

5. Food Processing Techniques

Food processing techniques significantly influenced the biogenic amine content in food (Jaguey-Hernández et al., 2021). Fermentation was an example of a food processing technique involving temperature, pH, time, and salt, which were key environmental factors affecting biogenic amine levels in food (Gardini et al., 2016). Strict control was necessary to reduce or inhibit biogenic amine-producing microbes, including using low or optimal temperatures to reduce microbial activity and optimal salt concentrations to prevent the growth or contamination of biogenic amine-producing bacteria (Mah et al., 2019; Ekici & Omer, 2020). Food products that are processed through drying at low temperatures (7.2°C), either natural drying with sea wind or using freeze-drying, are able to inhibit the growth of microbes that produce decarboxylase enzymes (Doeun et al., 2016; Makhamrueang et al., 2021). Therefore, appropriate food processing techniques were necessary to prevent increased biogenic amine content in food.

Reduction Methods of Biogenic Amine Contents in Food

The reduction methods of biogenic amine compounds were divided into three types: chemical, biological, and physical reduction. Several methods that have been applied to various types of foods are shown in Table 6.

Tested food products generally have high levels of biogenic amines, although still within safe limits. However, improper handling and storage have the potential to increase the levels of biogenic amine compounds already contained in the products, so appropriate methods are needed to control or reduce the levels of biogenic amines in these foods.

Chemical methods to reduce biogenic amine levels can be achieved in several ways, such as adding essential oils, acid whey, spices, hydrogen-rich water, cava lees, peracetic acid, and even reducing biogenic amine levels through dietary feed using pomegranate. Essential oils contain antibacterial, antifungal, and antioxidant compounds that can inhibit the growth of bacteria producing biogenic amines. El-Khabaz et al. (2017) successfully inhibited biogenic amine compounds in fish fillet by using essential oils. Clove oil can reduce histamine levels by 5.5%–14.75%, putrescine by 9.6–11.9%, cadaverine by 7.7–9.3%, and tyramine by 5.2–10.6%. Thyme oil can sequentially reduce histamine, putrescine, cadaverine, and tyramine levels by 7.25–20.0%, 12.5–16.4%, 10.4–22.9%, and 16.5–16.3%, respectively. Lemon oil can reduce histamine levels by 15.8%–29.3%, putrescine levels by 19.35%–34.1%, cadaverine levels by 15.8% –29.8%, and tyramine levels by 22.4%–25.1%. Besides essential oils, the ability to inhibit the growth of biogenic amine-producing microbes can also be obtained from spices. Jia et al. (2020) tested the inhibition of biogenic amine levels in goat meat sausages fermented by seven types of dry spices: star anise, amomum tsao-ko, clove, cassia, fennel, bay leaf, and nutmeg. All spices were proven to reduce biogenic amine levels, with maximum inhibition of 21.8% (tryptamine), 19.3% (putrescine), 27.5% (spermidine), 24.6% (2-phenylethylamine), 18.7% (tyrosine), and 24.4% (histamine), with the highest reduction achieved by cassia and clove spices. Bacteria producing biogenic amines can also be inhibited by adding acid or low pH. Cava lees, sediment obtained from the wine fermentation process containing high fiber levels, can trigger fermentation bacteria to produce acid that inhibits the growth of biogenic amine-producing bacteria. Hernández-Macias et al. (2022) investigated the effect of adding cava lees and cava lees with phenolic extract on fermented bread and sausages. The results showed that there was no significant difference in the reduction of biogenic amines in bread due to the concentration of cava lees used. However, in fermented sausages, the addition of cava lees reduced putrescine levels by 78% and cadaverine levels by 62%, while cava lees phenolic extract reduced putrescine and cadaverine levels by 40 and 21%, respectively. Meat is a

Table 6: Reduction Methods of Biogenic Amine Contents in Food

	Methods of Reduction	Food Products	Benefits and Extent of Reduction	References
Chemical	Essential Oil	Fish Fillet	Inhibits biogenic amine due to antibacterial, antifungal, and antioxidant compounds.	El-Khabaz et al. (2017)
	Dry Spices	Dry Fermented Mutton Sausage	Reduces biogenic amine levels by inhibiting the growth of producing bacteria through the properties of various spices.	Jia et al. (2020)
	Cava Lees	Fermented Sausage	Reduces biogenic amine levels through acid production during fermentation.	Hernández-Macias et al. (2022)
	Acid Whey	Beef and Fallow Deer Sausage	Reduces biogenic amine levels by lowering pH and inhibiting producing bacteria.	Kononiuk & Karwowska, (2020)
	Peracetic Acid	Chicken Meat	Potentially reduces biogenic amine levels when combined with proper storage methods like MAP.	Bertram et al. (2019)
	Hydrogen-Rich Water	Pickle Red Bit and Brine	Reduces biogenic amine levels in pickled products by inhibiting the formation during pickling.	Alwazeer et al. (2022)
	Grape Pomace Diet	Poultry Meat	Reduces biogenic amine levels by influencing the diet during the animals growth period.	Bennato et al. (2020)
Physical	High hydrostatic pressure	Semidried Fermented Sausage	Inhibits the growth of *Enterobacteriaceae* and reduces some biogenic amines. Spermine and spermidine are not affected.	Borges et al. (2020)
	Modified Atmosphere Packaging Radiation UV-C CO2	Tilapia (*Oreochromis niloticus*) Fillets	Prevents the increase in spermine and spermidine content. Histamine and putrescine are not affected	Lázaro et al. (2020)
	Water-Gas Ozone	Chicken Meat	Control the increase in putrescine and cadaverine levels. Biogenic amine- producing microbes not completely eliminated	Zakeri et al. (2021)
		Food Products	Benefits and Extent of Reduction	References
	Air Blast and Count Plate freezing	Cakalang Fish (*Katsuwonus Pelamis*)	Reduced histamine levels. Histamine is reduced to 0-3.9ppm by air blast, 0.1-0.3ppm by freezing of counting plates.	Mawaddah et al. (2023)
Microbial	*L. acidophilus* UCLM-104, *L. plantarum* UCLM-93 and *L. plantarum* UCLM-77	Raw Milk Manchego Cheese	Able to reduce the levels of tyramine, cadaverine, and histamine by 93.8%, 78.7%, and 73.7%	Ramos et al. (2024)
	Tetragenococcus halophilus strain (MJ4)	Saeu-Jeot (Salted Shrimp Sauce)	Prevents the activity of other bacteria that produce biogenic amine.	Kim et al. (2019)
	B. licheniformis CH7P22	Cheonggukjang	Lowers tyramine, and histamine levels.	Kim et al. (2023)
	L. brevis PK08	Baechu Kimchi	Lowers levels of tyramine (66,65%), and histamine (81.89%), also slightly putrescine, cadaverine, spermin, and spermidine level.	Lee et al. (2021)

product that naturally contains biogenic amines, and the type of meat affects the initial amount of biogenic amines in the product. In products like sausages, additives such as nitrite and salt are commonly used, which can interact and increase the carcinogenic potential of biogenic amines. Kononiuk & Karwowska (2020) found that the biogenic amine levels in fallow deer meat were higher than in beef, and acid whey obtained from the cottage cheese manufacturing process could be used as an alternative additive in beef and fallow deer sausages, which was better than nitrate and salt because it could reduce biogenic amine levels (histamine, cadaverine, tyramine, and putrescine) by up to 19% in beef sausages and 51% in fallow deer sausages, with cadaverine being the most significantly reduced biogenic amine. Acid whey works in the same way as cava lees by inhibiting or reducing biogenic amines through pH reduction. Other organic acids that can be used include peracetic acid, Bertram et al. (2019) reported that the use of peracetic acid in chicken meat did not significantly affect biogenic amine levels but needed to be combined with proper storage methods such as MAP, which could potentially reduce biogenic amine levels better. In addition to meat, research on inhibiting the formation of biogenic amine levels is also carried out on pickled beets and brine. Alwazeer et al. (2022) reported that the use of hydrogen-rich water could produce pickled beets with lower biogenic amine levels than regular water, with reductions obtained in beets and brine as follows: tyramine by 15.15 and 18.35%, tryptamine by 17.09 and 21.76%, putrescine by 21.64 and 19.5%, 2-phenylethylamine by 16.67 and 13.44%, and histamine by 27.65 and 22.7%. As explained earlier, biogenic amines can naturally be present in meat or raw materials, so the formation of biogenic amines can be inhibited since the animal's growth period. Bennato et al. (2020) successfully obtained chicken meat with low biogenic amine levels, namely putrescine 0.15mg/l, cadaverine (not detected), and tyramine 0.13mg/L, by providing a feed diet consisting of grape pomace to male Ross broiler chickens for 21 days.

Reduction of biogenic amines through physical methods can be done in several ways, such as high hydrostatic pressure, modified atmosphere packaging (MAP), and ozone treatment. Borges et al. (2020) conducted tests to reduce biogenic amine compounds by inhibiting the growth of *Enterobacteriaceae* through the high hydrostatic pressure process, which involves placing the sample in a vessel at a temperature of 10℃ submerged in high-pressure water. Based on the research conducted, it is known that the HPP method can inhibit the growth of *Enterobacteriaceae* and reduce the content of biogenic amines such as tryptamine, phenylalanine, putrescine, cadaverine, histamine, and tyramine in semi-dry fermented sausages. However, this method is less effective in controlling the production of spermine and spermidine. In contrast to HHP, the application of UV-C and Modified Atmosphere Packaging (MAP) on fish fillets can prevent the increase in spermine and spermidine content, but it is known that histamine and putrescine cannot be controlled with these methods because CO_2 in MAP is suspected to increase protein denaturation and UV-C radiation increases the oxidative decarboxylation of amino acids due to the catalysis of Fe^{3+} production (Lázaro et al., 2020). Additionally, in fish, there are usually other bacteria besides *Enterobacteriaceae*, namely lactic acid bacteria, which are more resistant to CO_2 and UV- C radiation and can also produce biogenic amines under microaerobic or anaerobic conditions. In addition to fish meat, the process of reducing microbes to prevent an increase in biogenic amine levels is also carried out by Zakeri et al. (2021) by washing freshly cut chicken meat with ozone water and sanitizing it with ozone gas before freezing and storage. In their research, it was found that although ozone cannot completely eliminate biogenic amine-producing microbes, the method can control the increase in putrescine and cadaverine levels in chicken carcasses, thus maintaining the levels contained in the carcasses during storage at safe levels. Furthermore, different freezing methods can affect histamine levels in fish. In the study by Mawaddah et al. (2023) it was found that fish subjected to air blast freezing had histamine levels of 0-3.9ppm, while fish subjected to count plate freezing had lower histamine levels of 0.1-0.3ppm.

The reduction and control of biogenic amine levels in food microbiologically are generally achieved by regulating the growth of biogenic amine-producing microbes or by adding microbes that can produce growth-inhibiting compounds or compete with biogenic amine-producing microbes. Microbiological methods for reducing biogenic amine compounds are preferred because they are easier and more efficient to perform. Microbiologically, biogenic amine control can be achieved by maintaining compounds so that they can still increase during storage but at safe concentrations and by reducing the production of biogenic amine compounds. In the study by Gentès et al. (2024), it was successful in maintaining the biogenic amine content at safe levels by storing it at a low temperature of 4°C and limiting bacteria that induce the decarboxylation process. In the study by Ramos et al. (2024), it was found that strains of *L. acidophilus* UCLM-104 isolated from Almagaro eggplants were able to reduce the levels of tyramine, cadaverine, and histamine by 93.8%, 78.7%, and 73.7%, respectively, in Manchego cheese products made from goat milk. In this study, other microbes such as *L. plantarum* UCLM-93 and *L. plantarum* UCLM-77 were also able to reduce biogenic amine levels, but both were not found during the ripening phase. In another study, *Tetragenococcus halophilus* strain (MJ4) isolated from anchovy sauce was able to alter the bacterial diversification so that other bacteria such as *T. muriaticus*, which are involved in biogenic amine production in shrimp sauce fermentation, could be prevented from their activities (Kim et al., 2019). If in previous studies bacteria reducing amines were isolated from different food materials than the samples tested, then in the study by Kim et al. (2023), bacteria reducing biogenic amines such as *B. licheniformis* CH7P22, *B. haynesii* CH7P24, and *B. velezensis* CH7P28 isolated from Cheonggukjang were applied to Cheonggukjang as well. The results obtained in their research showed that *B. licheniformis* CH7P22 is the most suitable isolate for controlling biogenic amine levels in the Cheonggukjang making process because it can degrade tyramine and histamine compounds and is less capable of producing biogenic amine compounds. This strain can reduce tyramine levels by up to 63%, histamine levels by up to 100%, and spermine by 59%. A similar study conducted by Lee et al. (2021), where 5 strains of lactic acid bacteria from various types of kimchi were used to reduce biogenic amine levels in Baechu (Napa Cabbage) Kimchi, showed that L. brevis PK08 bacteria, isolated with the highest reduction rates of biogenic amines, namely tyramine (66.65%) and histamine (81.89%), also slightly reduced putrescine, cadaverine, spermine, and spermidine levels. The results indicate that the use of biogenic amine reducing bacteria can effectively reduce the amount of harmful substances present in fermented foods. This can improve the safety and quality of the final product. However, there are some limitations that further research is needed to understand the mechanism of biogenic amine degradation to ensure the effectiveness and stability of these bacteria in reducing biogenic amines.

Conclusion

The majority of biogenic amine content in food found in Southeast Asia remained within the safe limits of maximum biogenic amine content in food. Biogenic amine factor consisted of internal factor such as amino acid, endogenous enzyme, and microbial content, and external factor such as hygiene, handling, preservative, processing technique, and microbial activity. Biogenic amine compounds can be controlled and reduced through chemical methods such as the addition of essential oils, as well as antimicrobial compounds that can inhibit the growth of bacteria producing biogenic amine compounds. Physical methods such as freezing and controlling the atmosphere during storage can also degrade biogenic amine compounds and inhibit the growth of spoilage bacteria producing biogenic amines. The most commonly used method is microbiological, involving the addition of isolates that can inhibit the growth of bacteria producing biogenic amines by acting as competitors or producing certain compounds. More analysis is needed on the content of biogenic amine compounds in food in Southeast Asia, especially fermented food products.

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Authors' Contribution

Bhakti Etza Setiani: Investigation, analysis, writing – original draft, proofed conception or design, critical revision, final approval of the version to be published. Yunianta: Proofed conception or design, critical revision, final approval of the version to be published. Elok Zubaidah: Proofed conception or design, critical revision, final approval of the version to be published. Agustin Krisna Wardani: Proofed conception or design, critical revision, final approval of the version to be published.

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