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REVIEW ARTICLE

A review: amino acids, biogenic amines, and microbial diversity in traditional asian fermented shrimp-based products

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ABSTRACT

Fermented shrimp-based products, primarily derived from *Acetes* spp., are globally consumed and play a crucial role in food quality and extending shelf stability. Fermentation establishes an environment that is unfavourable to spoilage microorganisms; however, natural fermentation stimulates the growth of different microorganisms derived from the shrimps or salts applied in the fermentation. Thus, the primary free amino acids and biogenic amines (BAs) were produced as a result of shrimp-based fermentation. This review aims to describe knowledge on biogenic amines, amino acids, and microbial diversity within fermented shrimp-based products, with a focus on those produced in Asia. Proteinases produced by fermenting microorganisms break down the proteins into smaller peptides and amino acids, and the microbial decarboxylation of amino acids causes the formation of biogenic amines (BAs), which pose health risks. Various analytical approaches have been studied, including high-performance liquid chromatography (HPLC) for quantifying amino acids and biogenic amines. The profiling of diversity and function of microbes present in a wide range of fermented shrimp-based products can be examined in detail using molecular and next-generation sequencing (NGS). Additionally, this review examines the functional contributions of these elements, addresses challenges, and proposes future research directions. Further research on fermented shrimp-based products is essential for advancing food science and promoting human health benefits.

1. INTRODUCTION

Asia is the most multicultural and resource-rich continent in terms of fermented shrimp-based products, with Asian countries being particularly notable for their widespread distribution in both urban and rural markets (Arcales & Alolod, 2018). The nomenclature of fermented shrimp-based products varies following local traditions, usually leading to different terms for the same or similar products, such as *Belacan* in Malaysia and Brunei, *Terasi* in Indonesia, *Kapi* in Thailand, *Bagoong-alamang* in the Philippines, *Saeu-jeot* in Korea, and *Haam ha* in China (Kim et al., 2014; Belleggia & Osimani, 2023). These products differ widely in aroma, colour, and texture due to variations in ingredients, methods of production, culinary traditions, consumer inclinations, and local climate (Zang et al., 2019). In Malaysia, fermented shrimp-based products such as *Belacan* have traditionally been used to enhance taste, improve nutrition, and provide health benefits in numerous dishes, like *asam laksa* and *belacan* fried rice (Choong et al., 2012; Abidin et al., 2020). Typically, shrimp paste appears as a greyish-pink to greyish-purple or reddish-brown paste, fermented in high salt concentrations and valued for its pronounced umami flavour. Proteolysis during fermentation significantly shapes flavour and nutrition as shrimp proteins are hydrolysed into peptides and amino acids by endogenous proteinases and halophilic bacteria (Gildberg & Thongthai, 2001). Further reactions, including the Maillard reaction and fat oxidation, intensify the fermented shrimp-based products characteristic flavour. Peptides and amino acids, influenced by the hydrophobicity of amino acid side chains, are central to the distinct taste profile of fermented shrimp products (Mehta et al., 2012; Herlina & Setiarto, 2024).

Acetes spp. is a small-type marine species remarkable for its flat sides and distinct long eye stalks, which enhance its visibility in turbid waters, thus favouring habitats with high water quality. Besides, it is abundant in protein, minerals, and chitin, rendering it a significant food resource (Xu et al., 2005). Its small shell and thin meat layer make it particularly suitable for processing into shrimp sauces or pastes, establishing it as a primary raw material in fermented shrimp-based condiment production. During fermentation, carbohydrates undergo oxidation, producing organic acids, alcohol, and carbon dioxide, which create a natural preservation effect that inhibits the proliferation of spoilage organisms and pathogenic microbes and enhances the shelf life of products. Both lactic acid and acetic acid are organic acids essential for end-fermented products, as they create an acidic environment that inhibits the proliferation of numerous pathogenic and spoilage microbes (Medina et al., 2016; Narzary et al., 2021). This process employs a preservation technique that uses microorganisms and salt in order to extend the shelf life of food by altering its composition (Teng et al., 2021). Fermentation on shrimp preserves the product by creating a hostile environment for spoilage-causing microorganisms, allowing it to remain fresh and edible for longer periods (Speranza et al., 2021). Despite the high nutritional value and bioactivities of fermented shrimp-based products, the products contain compounds such as sodium chloride, biogenic amines (BAs), and N-nitroso compounds (NOCs), which may pose health risks (Cai et al., 2017; Wu et al., 2022). Although consumers do not commonly consume them in large quantities, it is crucial to reduce or eliminate these undesirable compounds to minimise health risks; this is especially important for excessive sodium chloride intake, which necessitates the use of low-salt production techniques (Campo et al., 2020). BAs, formed by the microbial decarboxylation of amino acids, are low-molecule-weight biomolecules with basic organic functionalities. Controlling the formation of BAs through effective microbial management is essential to ensuring the safety and quality of fermented shrimp-based products (Kannan et al., 2020). In the fermentation process of shrimp-based production, proteolytic bacteria play a key role in breaking down proteins into peptides and free amino acids, significantly increasing these compounds. The peptides and amino acids enhance nutritional value but also contribute to the paste's unique taste, which largely depends on the hydrophobicity of the amino acid side chains. The primary free amino acids commonly identified in fresh and fermented shrimp include glycine, arginine, alanine, proline, lysine, leucine, and glutamic acid, which contribute distinct flavour notes and enrich the overall taste profile (Herlina & Setiarto, 2024). Fermented shrimp-based product paste, like shrimp paste (*Belacan*) in Malaysia, is generally completed by the natural fermentation of the shrimp (*Acetes* spp.) and salt mix at an ambient temperature for 1–4 weeks. The natural fermentation of shrimp paste stimulates the growth of different microorganisms derived from the shrimps or salts applied in the fermentation (Jung et al., 2013; Lee et al., 2014). Most of these microorganisms, such as *Bacillus, Achromobacter, Staphylococcus, Vibrio, Photobacterium, Micrococcus,* and *Tetragenococcus*, are prevalent during shrimp paste fermentation, presumably due to their elevated halotolerance (Udomsil et al., 2010; Lee et al., 2015). Furthermore, halophilic bacteria contribute significantly to protein breakdown and the development of the shrimp paste's distinctive flavour and aroma. However, the traditional culture-based approach is practical for detecting particular types of microorganisms since most bacteria are unsuitable for cultivation in specified nutrient media (Nam et al., 2012). These microorganisms critically function in flavour compositions and impact the comprehensive quality of the final shrimp paste (Lee et al., 2014). Therefore, numerous studies have been conducted to examine the bacterial community's sequences and understand their involvement in flavour production (Liu et al., 2015; Huang et al., 2018).

2. FACTORS FOR FERMENTED SHRIMP-BASED PRODUCTS IN ASIA

The unique flavour of shrimp paste is derived from a natural long-term fermentation process, during which proteins undergo extensive hydrolysis. This breakdown of proteins into smaller peptides and amino acids is facilitated by both endogenous proteinases—enzymes present within the shrimp itself—and microbial proteinases produced by fermenting microorganisms. The synergistic action of these enzymes plays a crucial role in shaping the paste's distinctive umami-rich flavour and dark colour. Proteins are broken down into free amino acids, including glutamic and aspartic acids, which contribute significantly to the paste's savoury and complex taste profile. Furthermore, the fermentation process not only enhances the flavour but also influences the final texture and colour of the paste, which may vary depending on the specific microbial communities involved and environmental conditions (Dissaraphong et al., 2006; Wang et al., 2018; Ohshima et al., 2019). Figure 1 highlights the classification of fermentation.

2.1. Fermentation duration of fermented shrimp-based products

Fermented shrimp-based products vary in fermentation duration according to cultural traditions and dietary preferences, generally following three stages. In the fresh fermentation stage, shrimp undergo a brief fermentation period, typically a few days to weeks, retaining much of their original form and acquiring a mild flavour. An example is *Belacan* from Malaysia, which ferments for 1–14 days before being sun-dried (Khudair et al., 2023). Second, for semi-fermented shrimp, the process extends to several weeks or months, producing a paste or liquid with robust, complex flavours; *Saeuojeot* from Korea, a pickled shrimp delicacy, exemplifies this stage, developing a pungent aroma and deep savouriness after weeks to months of fermentation (Kim et al., 2014). Finally, in fully fermented shrimp, the longest stage in

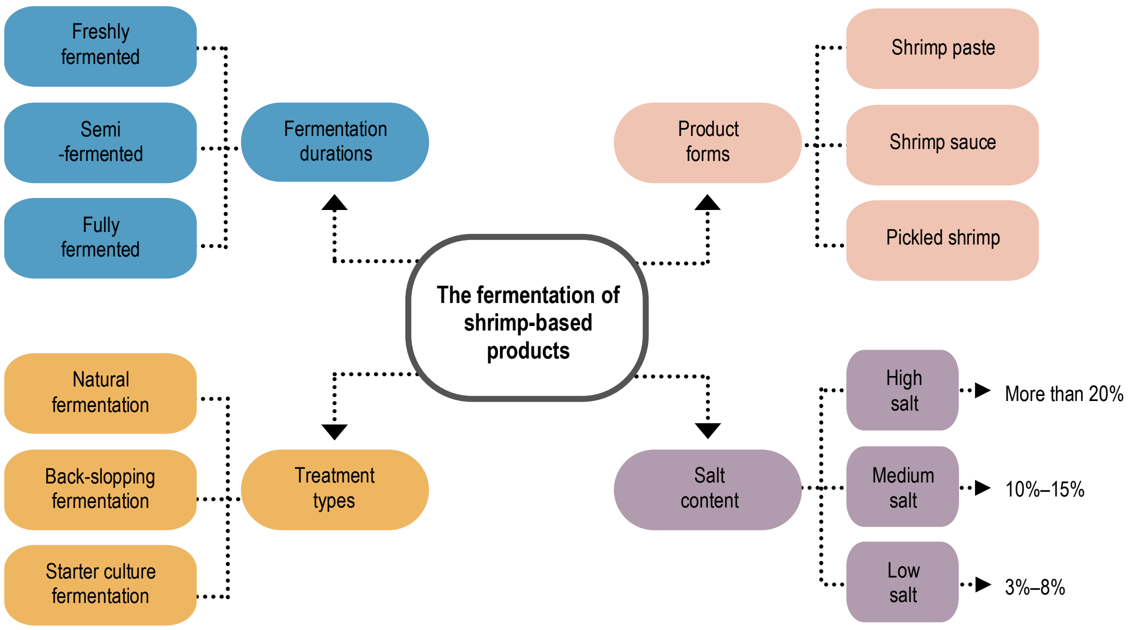

Figure 1: The classification of fermentation

shrimp-based product fermentation is until fermented shrimp are completely mature, resulting in products with intense, umami-rich flavours integral to various Asian cuisines. A notable example is *Xiā jiàng*, a shrimp paste product from China, which ferments for a few months to a few years (Li et al., 2021). Each stage reflects unique processing methods that shape the texture and taste of the final product.

2.2. Product form of fermented shrimp-based products

Traditionally, fermented shrimp-based products use shrimp, typically Acetes sp., as their primary ingredient. The production process involves grinding the shrimp, mixing with salt, fermentation, and a sun-drying process (Kim et al., 2014). Fermented shrimp-based products can take various forms, including whole pieces, pastes, or liquids. Shrimp paste, in particular, is a brownish product formed by combining low-value marine shrimp with a specific proportion of salt and fermenting it for several days to even years. This process yields a condiment that enjoys widespread popularity throughout Asia (Han et al., 2023; Cai et al., 2024). Its name and form vary by country, with more than six distinct variants identified across the region, as highlighted in Table 1.

Shrimp paste, an essential ingredient in many Asian cuisines, varies not only in taste and texture but also in its local nomenclature. The regional differences reflect the unique fermentation methods, environmental conditions, and cultural preferences that influence the production of shrimp paste. In Malaysia and Brunei, it is called *belacan*, a dark, dense paste known for its robust umami flavour; it is typically sun-dried and moulded into blocks. In Indonesia, the paste goes by the name *terasi*, which can range from coarse to smooth in texture and is often used as a base for sambal. Thailand's version, *kapi*, is generally more pungent, fermented with krill, and commonly incorporated into dishes like Thai curry pastes and *namprik*. In the Philippines, shrimp paste is called *bagoong-alamang*, a wet, salty variant that retains more liquid than its counterparts, often paired with green mango or used as a condiment. Korean *saeujeot* differs from other shrimp pastes in that it involves fermenting small shrimp in brine rather than making a paste; it is commonly used to flavour kimchi or served as a condiment. In China, *haam ha*, known for its strong, pungent odour, plays a vital role in traditional southern Chinese dishes such as shrimp sauce pork, or stir-fried vegetables. These variations reflect the diversity and cultural significance of shrimp paste across Asia, with each region tailoring its production methods to local tastes and culinary traditions. Shrimp sauce from shrimp-like zooplankton, usually found in large amounts in Southeast Asian seas, is one of the popular umami-rich condiments produced in Thailand. Krill is preferred to be used for making shrimp sauce as compared to other types of shrimp, since it spoils rapidly. To produce the shrimp sauce, frozen krill is added with 30% salt. After storing the mixed krill at 5 °C for three months without stirring, it is squeezed, filtered, and boiled to make a sauce (Hajeb & Jinap, 2013). Fermented krill sauce, rich in free amino acids, has a more profound taste compared to soy sauce. This fermented sauce has a distinctive krill flavour and a strong umami taste.

2.3. Salt content of fermented shrimp-based products

Salt is one of the most commonly used raw components in fermented shrimp-based production. These products are categorised into four groups based on the amount of salt added: high-salt (more than 20% of the total weight), medium-salt (usually between 10% and 15%), low-salt (between 3% and 8%), and even salt-free products. Salt plays a miscellaneous role in the manufacturing process and serves as a selective medium in the fermentation of shrimp-based products, performing as a natural preservative by inhibiting water activity to reduce the growth of spoiling bacteria and diseases (Kuda et al., 2012). Simultaneously, the environmental conditions created by the salt primarily support the growth of halotolerant or halophilic bacteria. In the fermentation of shrimp-based products, salt, with halotolerant lactic acid bacteria (LAB), acts as a preservative. Halophilic bacteria, which decompose proteins, carbohydrates, and fats during both aerobic and anaerobic processes, develop distinct flavours in shrimp-based products (Sumardianto et al., 2024). Thus, salt serves a dual role in the fermentation of shrimp paste, acting as a preservative, enhancing its texture, and preventing it from becoming unduly mushy (Ma et al., 2022). However, current dietary trends highlight the necessity of limiting salt intake. As a result, there is an increasing demand for fermented shrimp-based products with reduced or free salt. Electrodialysis techniques are performed to reduce the salt level in shrimp sauce. Nonetheless, the results revealed a trade-off: while electrodialysis treatment does reduce the salt level, it raises the energy cost of production and dramatically reduces the output of shrimp sauce (Chindapan et al., 2009). The starter cultures method is one approach to tackling difficulty in the food fermentation industry. These cultures can expedite protein hydrolysis during fermented shrimp production, change the composition of microorganisms, and decrease the fermentation time. As a result, the fermentation process requires less salt (Shivanne Gowda et al., 2016).

2.4. Treatment type of fermented shrimp-based products

Fermented shrimp-based is produced in two ways: natural and starter culture fermentation. Although fermented shrimp has a long history, until the advent of current microbial technologies, all fermented shrimp were created through natural fermentation. In this conventional approach, the beginning and guidance of the fermentation process rely mainly on naturally transpiring bacteria discovered in the environment and on the shrimp itself (Ma et al., 2022). Natural fermentation is well-known for producing a wide range of unique flavours. However, it also presents several obstacles. Considerations include the stability of product quality, longer fermentation durations, reliance on unique production environments in different countries, and potential food safety concerns (Wang et al., 2021).

Natural fermentation can be accelerated using an approach called "back-slopping" to alleviate some of these issues. This procedure entails retaining a miniature quantity of previously effectively fermented material and incorporating it into subsequent batches. This allows for the stability of microbes across various batches of fermented shrimps,

Table 1: Traditional Asian fermented shrimp-based products

Country	Product name	Species	Salt (%)	Fermentation period	Product processing	References
Malaysia	Belacan (shrimp paste)	*Acetes* spp.	≥ 15	1–2 weeks	• Pounding, fermentation, and salting • Fermentation in sealed containers	(Khudair et al., 2023)
Malaysia	Cincalok (pickled shrimp)	*Acetes* spp.	20	20–30 days	• Salting • Fermentation in earthenware jars covered with a piece of cloth	(Huda, 2012)
Indonesia	Cincalok (shrimp sauce)	*Acetes* spp.	4.76	0–180 days	• Salting • Fermentation in glass containers covered with lids	(Nofiani et al., 2021)
Indonesia	Terasi (shrimp paste)	*Atya* spp. *Acetes* spp.	1–2	• Pre: 1–3 days • 1–3 weeks	• Sun-drying and resting stage • Salting, repeated milling, sun-drying, and milling (twice)	(Prihanto & Muyasyaroh, 2021)
Thailand	Kapi (shrimp paste)	*Acetes vulgaris*	16.67	30 days	• Salting, draining, and pounding • Fermentation in earthen jars	(Pongsetkul et al., 2022)
Korea	Saeuojeot (pickle shrimp)	*Acetes* spp.	30–40	4–5 months	• Salting, freeze-drying, and pounding • Fermentation in plastic sacks	(Kim et al., 2014)
Brunei	Belacan (shrimp paste)	*Acetes* spp.	15–20	Overnight	• Fermenting, ripening, and salting • Fermentation in plastic sacks	(Kim et al., 2014)
Philippines	Bagoong-alamang (shrimp paste)	*Atya* spp. *Acetes* spp.	20–25	3–12 months	• Washing (brine solution) • Fermentation in jars by leaving a headspace of 1–3 inches	(Olympia, 1992; Pamungkaningtyas, 2023)
China	Haam ha (shrimp paste)	Grasshopper sub shrimp	30–35	several months	• Salting • Fermentation in pots sealed using triple-layered gauze	(Li et al., 2021)
China	Xiā jiàng (shrimp sauce)	*Acetes chinensis* sp.	30	3 years	• Salting. • Fermentation in tanks covered using triple-layer gauze	(Zhu et al., 2019)

reducing the effect of changes in the environment on the quality of the product (Whittington et al., 2019).

A starter culture is a carefully chosen mixture of microorganisms used to increase the effectiveness of the fermentation process. The food industry uses a variety of microbial cultures to ensure the production of safe and high-quality products. These microbes commonly derive from naturally fermented foods produced using conventional methods (Pereira et al., 2019). This approach enables the isolated microbes to quickly adapt to the fermentation-specific environmental conditions, allowing instantaneous reproduction. As a result, they play a crucial role in reducing food deterioration and inhibiting the proliferation of pathogenic microbes (Laranjo et al., 2019). Starter cultures can contain both bacteria and fungi, with each adding unique characteristics to the fermentation process. Yeasts within the starter culture assist in carbohydrate fermentation by releasing aromatic chemicals that significantly affect the flavour of fermented shrimp (Han et al., 2023).

The most notable traditional Asian fermented shrimp-based products are outlined in Table 1. For each traditional product, the shrimp species, salt concentration, treatment duration, and traditional product processing are provided without further description in the text.

3. THE AMINO ACIDS IN ASIAN FERMENTED SHRIMP-BASED PRODUCTS

The 17 standard amino acids, classified by their chemical properties, include nonpolar aliphatic (valine, glycine, isoleucine, alanine, proline, leucine), aromatic (phenylalanine, tyrosine), polar uncharged (serine, threonine, cysteine), positively charged (histidine, lysine, arginine), negatively charged (glutamic acid, aspartic acid), and sulphur-containing (methionine) amino acids, as illustrated in Table 2.

During the production of fermented shrimp-based products, proteolytic bacteria break down proteins into peptides and amino acids, leading to an increase in these compounds (Daroonpunt et al., 2016). Peptides and amino acids influence the flavour profile, with taste mainly dependent on the hydrophobicity of the amino acid side chains (Pongsetkul et al., 2022; Herlina & Setiarto, 2024).

The kinetic perspective highlights the transition from fresh shrimp to a fully matured product, illustrating both flavour development and nutritional changes, as summarized in Table 3. At the fresh stage (0 days), the primary free amino acids identified in fresh and fermented shrimp include glycine, proline, arginine, alanine, leucine, glutamic acid, and lysine. Fresh shrimp contain approximately 3.6% total free amino acids (Peralta et al., 2005). During this stage, proteolysis is produced by the shrimp's endogenous enzymes, resulting in a soft flavor profile characterized by a light sweetness and a mild umami richness (Kurnianto et al., 2025).

During early fermentation (1–2 weeks), following salting and fermentation, there is a significant dominance of glutamine, leucine, lysine, and citrulline (Peralta et al., 2005). Proteolytic activity significantly increases, leading to high concentrations of hydrophilic amino acids, particularly glutamic acid and aspartic acid (Helmi et al., 2022). Also, sweet-tasting amino acids, such as glycine and alanine, increase, while branched-chain amino acids (leucine, isoleucine, and valine) begin to accumulate (Park et al., 2023). These biochemical changes result in a significant enhancement of umami intensity.

During the mid-fermentation stage (1–3 months), total free amino acid (FAA) levels typically increase to between 6% and 8% (Peralta et al., 2005). There is a significant accumulation of hydrophobic amino acids, which can introduce a slight bitterness when present in higher concentrations (Herlina & Setiarto, 2024), and essential amino acids such as arginine, lysine, and histidine increase (Prihanto & Muyasyaroh, 2021). The microbial-dominated proteolysis contributes to a more complex flavor profile, which has a prominent umami and slight bitter taste (Daroonpunt et al., 2016).

By the late fermentation stage (6–12 months), FAA concentrations naturally stabilize due to microbial conversion into volatile nitrogenous compounds. Glutamic acid and aspartic acid levels remain high, therefore preserving strong umami characteristics (Peralta et al., 2005). Deamination processes become increasingly prominent, resulting in higher concentrations of ammonia and flavour-active compounds associated with fully matured shrimp paste (Prihanto & Muyasyaroh, 2021).

Therefore, these variations are expected to mean that the free amino acid content of fermented shrimp-based products is significantly different between countries, specifically when the raw materials, fermentation periods, and production methods vary. In fermented shrimp-based products, the four predominant amino acids are arginine, glutamic acid, leucine, and aspartic acid. Notably, a more elevated concentration of glutamic acid is observed in fermented shrimp-based products inoculated with starter cultures compared to those that undergo natural fermentation. Both aspartic acid and glutamic acid contribute to the

Table 2: Amino acid in traditional Asian fermented shrimp-based products

Country	Product name	Species	Amino acid (mg/kg)																	References
			Gly	Ala	Val	Leu	Ile	Pro	Phe	Tyr	Ser	Thr	Cys	Lys	Arg	His	Asp	Glu	Met	
Malaysia	Belacan (shrimp paste)	*Acetes* spp.	15.7	17	14.2	24.5	12.6	11.7	13	10.1	9.51	12.9	ND	24.7	10.4	4.91	28.4	52.8	9.23	(Padilah et al., 2018)
Brunei	Belacan (shrimp paste)	*Acetes* spp.	30.1	32.7	27.2	47.0	24.2	22.5	25.0	19.4	18.3	24.8	ND	47.4	20.0	9.43	54.6	101	17.7	(Kim et al., 2014)
Thailand	Kapi (shrimp paste)	*Acetes vulgaris*	3.66	5.66	2.64	4.05	1.18	5.01	1.43	1.69	0.93	0.03	0.12	4.38	3.14	0.59	8.51	18.18	1.16	(Pongsetkul et al., 2017)
Indonesia	Terasi (shrimp paste)	*Atya* spp. *Acetes* spp.	11	18	12.9	22	12.2	11.8	15.1	10.5	17.8	12.5	ND	19.3	21.9	48.9	25.6	42.1	ND	(Prihanto & Muyasyaroh, 2021
Korea	Saeuojeot (pickle shrimp)	*Acetes* spp.	17.0	13.6	13.2	20.00	11.7	12.6	12.5	8.78	8.31	11.8	ND	19.0	18.9	4.39	29.3	42.9	8.11	(Kim et al., 2014)
Philippines	Bagoong-alamang (shrimp paste)	*Atya* spp. *Acetes* spp.	30.3	14.9	31.3	56.5	27.7	22.4	19.2	9.12	9.29	13.9	ND	43.3	38.8	0.5	0.47	0.9	10.6	(Herlina & Setiarto, 2024)
China	Xiā jiàng (shrimp sauce)	*Acetes chinensis* sp.	583	371	900	1479	1447	ND	1561	101	752	925	231	1637	395	518	1672	1791	254	(Zhu et al., 2019)

Values are expressed as mean; ND not detected. Amino acids are: Gly (Glycine), Ala (Alanine), Val (Valine), Leu (Leucine), Ile (Isoleucine), Pro (Proline), Phe (Phenylalanine), Tyr (Tyrosine), Ser (Serine), Thr (Threonine), Cys (Cysteine), Lys (Lysine), Arg (Arginine), His (Histidine), Asp (Aspartic acid), Glu (Glutamic acid), & Met (Methionine)

Table 3: Quantitative changes in free amino acid (FAA) content during shrimp fermentation

Stage	Fermentation period	Sample	FAA content	Dominant Amino Acids	Flavour characteristics	References
Fresh (0 days)	0 days	Terasi with Tetragenococcus halophilus inoculation (shrimp paste)	3.6 %	Gly, Pro, Ala, Glu, Arg	Mild sweetness (Gly, Ala) with slight umami (Glu)	(Kurnianto et al., 2025)
Early fermentation (1-2 weeks)	21 days	Terasi with Tetragenococcus halophilus inoculation (shrimp paste)	6.85%	Increase in Glu, Asp, Gly, Ala; initial increase in Leu, Ile, Val	Enhanced umami; sweet notes from Gly and Ala	(Kurnianto et al., 2025)
	6 days	Low-salt (12%) shrimp paste	0.13 µg/g			(Gu et al., 2025)
	12 days	Low-salt (12%) shrimp paste	30.82 µg/g			(Gu et al., 2025)
Mid fermentation (1-3 months)	30 days	Dry Kapi (shrimp paste)	49.17 mg/g	Increase in Leu, Ile, Val, Arg, Lys, His; continued high Glu, Asp	Strong umami (Glu, Asp) with slight bitterness (Leu, Val)	(Pongsetkul et al., 2017)
	30 days	Low-salt fermented shrimp paste	34.6 mg/g			(Cai et al., 2017)
Long-term storage fermentation (6-12 months)	12 months	Shrimp paste with Bacillus. subtilis inoculation (shrimp paste)	70.8 mg/g	Glu, Asp remains high; some decrease in Lys, Leu; increase in ammonia nitrogen	Rich, mature umami; complex savoury–bitter profile	(Pongsetkul et al., 2023)

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taste of shrimp pastes (Prihanto & Muyasyaroh, 2021).

Glutamic acid, in the form of its sodium salt, monosodium glutamate (MSG), imparts a flavour, making it a pivotal flavouring component. Even though fermented shrimp-based products have various nutritional benefits, they are typically consumed in small quantities as flavour enhancers (Kurihara, 2015). Therefore, fermented shrimp-based products do not contribute significantly to meeting daily nutritional requirements.

4. THE BIOGENIC AMINES IN ASIAN FERMENTED SHRIM-BASED PRODUCTS

Biogenic amines (BAs), including histamine, tyramine, putrescine, cadaverine, agmatine, spermidine, and spermine, are low-molecular-weight organic nitrogenous compounds produced primarily through the enzymatic decarboxylation of specific amino acids (Tofalo et al., 2016; Del Rio et al., 2024). These compounds occur naturally in plants, microorganisms, and animal cells, where they play essential physiological roles such as acting as precursors for hormones, regulating cell growth, and modulating neural activity (Wójcik et al., 2021). However, when present in high concentrations, particularly in food, BAs may exert toxicological effects on human health (Feddern et al., 2019). Due to these risks, the presence and concentration of BAs in fermented foods have become a critical food safety concern, as summarized in Table 4.

Bacterial strains expressing decarboxylase activity produce BAs through free amino acid decarboxylation (Pongsetkul, 2018). The elevated levels of biogenic amines are correlated to the bacteria's presence of decarboxylation capabilities, exacerbated by poor hygiene practices and inadequate food safety (Doeun et al., 2017). Three categories of factors influence the formation of biogenic amines: those of the raw material (pH, chemical composition), those associated with the storage and processing conditions of the products (raw, dried, cooked, fermentation conditions, sanitary processing conditions, packaging methods and conditions, storage temperature and duration), and microbiological contamination (presence of strains exhibiting decarboxylase activity) (Shi et al., 2023). Therefore, ensuring adequate hygienic conditions is essential for controlling amine-positive microbial strains (Wójcik et al., 2021).

High-salt fermented shrimp-based products commonly contain bacterial genera such as *Tetragenococcus, Psychrobacter, Staphylococcus*, and *Lysinibacillus*, which produce BAs through the decarboxylation of amino acids like tyrosine, histidine, and ornithine. Spoilage-related bacteria, including *Vibrio, Pseudoalteromonas*, and *Photobacterium*, are active early in fermentation; however, their presence tends to decrease over time due to environmental changes and competition with halotolerant and lactic acid-producing bacteria that dominate later stages. The ability of halotolerant bacteria to secrete extracellular proteases and peptidases gives them a competitive ecological advantage (Yao et al., 2023), efficiently degrading proteins into peptides and free amino acids that support their growth while enriching the umami profile of the product (Pongsetkul, 2018). By dominating the microbial community in such selective environments, halotolerant bacterial species effectively suppress the growth of non-halophilic spoilage organisms (Dhar et al., 2022). *Jeotgalicoccus* and *Sporosarcina*, for instance, have been identified as notable producers of biogenic amines in various types of fermented shrimp-based products (Sang et al., 2020; Helmi et al., 2022). The result is the formation of biogenic amines like histamine, tyramine, and putrescine, which can accumulate in food products under unsanitary conditions, potentially leading to food safety hazards (Fatih & Yesim, 2007; Costantini et al., 2011). Ensuring strict hygiene practices can mitigate the risks associated with these harmful microbial activities.

Table 4: Biogenic amines in traditional Asian fermented shrimp-based products

Country	Product name	Species	Fermentation period	Biogenic amines (mg/kg)									References
				Him	Tym	Put	Cad	Spd	Spm	Typ	Phm	Total	
Malaysia	Belacan (shrimp paste)	Acetes spp.	NA	57.6	8.64	137	50.1	ND	ND	ND	ND	243	(Padilah et al., 2018)
Thailand	Kapi (shrimp paste)	Acetes vulgaris	6 months	32.87	4.52	24.23	31.70	ND	ND	52.65	ND	145.97	(Pongsetkul et al., 2022)
			12 months	61.61	8.41	75.10	43.50	ND	ND	88.10	6.60	283.32	
Indonesia	Terasi (shrimp paste)	Acetes spp.	NA	29.0	191	609	428	ND	ND	17.0	ND	1274	(Mery et al., 2021)
China	Haam ha (shrimp paste)	Grassho -pper sub shrimp	3 years	36.35	126.29	140.19	34.73	ND	ND	131.46	ND	469.02	(Li et al., 2021)

Values are expressed as mean; ND not detected.

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Consequently, BAs are frequently used as an indicator of food quality and safety.

4.1 Toxic activities of biogenic amines

BAs can be classified based on various criteria. By chemical structure, two primary groups exist: aliphatic amines, including cadaverine, putrescine, and aromatic amines (Kannan et al., 2020). Aromatic amines are further split into those with a benzene ring, such as β-phenylethylamine and tyramine, and those with a heterocyclic nucleus, like tryptamine and histamine (Erdag et al., 2018). Additionally, classification occurs based on the number of amino groups present. Monoamines, such as tyramine and β-phenylethylamine, contain one amino group, while diamines, including tryptamine, histamine, cadaverine, and putrescine, possess two (Wójcik et al., 2021).

Spermine and spermidine, while originally grouped with BAs, present considerable differences in their biosynthesis and physiological functions, leading to their classification as a separate group (Kalač, 2014). Spermine and spermidine are aliphatic polyamines derived from the enzymatic decarboxylation of ornithine or arginine, with putrescine serving as a precursor (Jaguey-Hernandez et al., 2021; Choińska et al., 2022). Specifically, putrescine can be formed from arginine through the decarboxylation of ornithine or agmatine, or via citrulline (Fabroni et al., 2020). The synthesis of these polyamines is a complex biological process, often regulated by environmental factors such as temperature, where cold stress has been observed to upregulate the enzymes involved in putrescine biosynthesis, leading to its accumulation (Fabroni et al., 2020). These polyamines exist in only trace amounts in food and do not pose health risks (Del Rio et al., 2018). Among BAs, tyramine and histamine hold the highest toxicity (Wójcik et al., 2021).

Histamine, a heterocyclic monoamine, is widely recognised for triggering adverse symptoms known as “histamine poisoning” when its levels rise in food, which leads to a range of adverse symptoms such as tingling of the tongue, rash, vomiting, diarrhoea, burning sensations, headaches, dizziness, nausea, lowered blood pressure, vasodilation, intracranial bleeding, palpitations, and respiratory difficulties.

These symptoms typically appear within hours of consumption and can persist for days. The severity of these reactions is often dose-dependent, with higher concentrations of histamine leading to more pronounced physiological disturbances (Del Rio et al., 2018). Conversely, other biogenic amines such as putrescine and cadaverine, while less acutely toxic, can potentiate the effects of histamine and contribute to the overall toxicological profile of fermented products (Oktariani et al., 2022). High histamine concentrations frequently occur in fermented shrimp-based products from the *Acetes* species due to accelerated enzymatic maturation. European regulations (Commission Regulation [EC] No. 1441/2007) establish allowable histamine levels of 100–200 mg/kg in unprocessed shrimp, with fermented products permitted up to 400 mg/kg. In contrast, the U.S. FDA applies a stricter limit of 50 mg/kg for shrimp and related seafood products. Despite these defined thresholds, there remain no specific regulatory standards governing histamine levels in other food categories, highlighting gaps in international food safety frameworks (Reinholds et al., 2020; Wójcik et al., 2021).

Tryptamine, another toxic amine, elevates blood pressure and primarily occurs in sausages and meat products—both β-phenylethylamine and tryptamine are linked to migraines due to their vasoconstrictive effects. Furthermore, amines reacting with nitrites produce nitrosamines, carcinogenic compounds (Ruiz-Capillas & Herrero, 2019). The accumulation of biogenic amines, particularly tyramine, has been implicated in genotoxic effects on intestinal cells and may promote intestinal cancer (Del Rio et al., 2018). This risk is heightened by the presence of multiple biogenic amines that can saturate detoxification pathways, alongside the potential for increased nitrosamine formation during traditional fermentation and heating processes (Setiarto & Herlina, 2024). This risk grows when foods rich in biogenic amines and preserved with nitrite or nitrate salts undergo consumption. The danger increases with heating, which promotes reactions between amines and nitrogen compounds, leading to nitrosamine formation. Histamine, putrescine, and cadaverine act as psychoactive amines, mimicking neurotransmitters and influencing the nervous system, potentially worsening hypertension (Wójcik et al., 2021).

The toxic effects of histamine and tyramine intensify in the presence of aliphatic diamines like cadaverine and putrescine. While putrescine and cadaverine generally cause mild symptoms, such as tachycardia, their interaction with histamine significantly increases toxicity (Zaman et al., 2009).

4.2 Detection of biogenic amines

BAs have been detected using various analytical approaches, ranging from traditional chromatographic techniques to better modern industry innovations. Considering their potential toxicity at high levels, reliable detection and measurement of biogenic amines (BAs) in food products is critical for guaranteeing food safety and quality, as shown in Figure 2.

Chromatographic techniques, particularly high-performance liquid chromatography (HPLC) and gas chromatography (GC), are widely applied for BAs detection due to their high sensitivity and specificity. HPLC, often

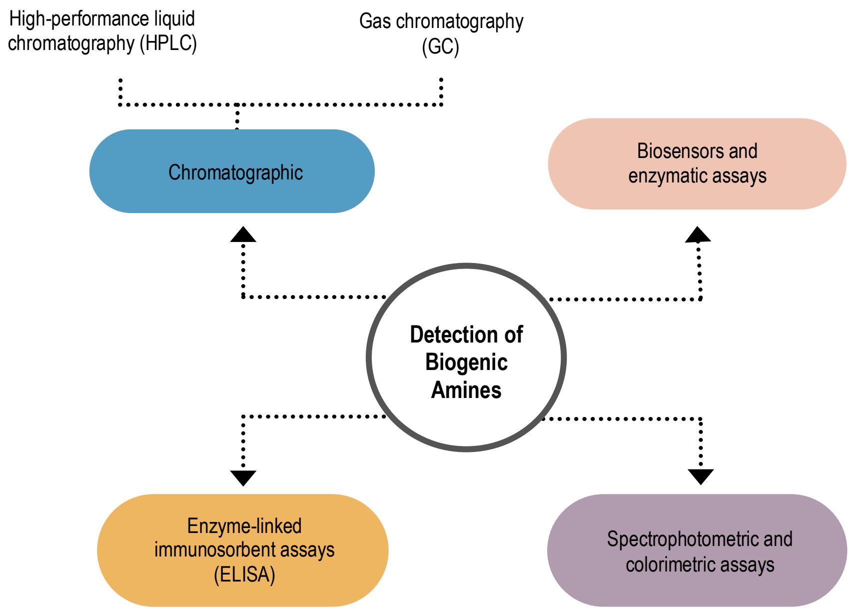

Figure 2: Detection of biogenic amines

coupled with ultraviolet (UV) or fluorescence detectors, is frequently employed for the separation and quantification of biogenic amines in fermented foods, such as fish, cheese, and wine (Tofalo et al., 2016). This method requires sample derivatisation, typically with dansyl chloride or benzoyl chloride, to improve detection sensitivity and facilitate amine identification (Latorre-Moratalla et al., 2012). Similarly, gas chromatography, usually combined with mass spectrometry (GC-MS), has been employed for detecting volatile biogenic amines like putrescine and cadaverine in various food matrices. Although GC-MS offers excellent sensitivity and resolution, it often requires complex sample preparation and derivatisation, making it more labour-intensive than HPLC (Matos & Genualdi, 2024).

In recent years, biosensors and enzymatic assays have gained attention as rapid and cost-effective alternatives for BAs detection. These methods rely on the interaction between BAs and specific enzymes, such as amine oxidase or diamine oxidase, which catalyse the oxidation of amines, producing measurable signals. Amperometric and optical biosensors have been developed to detect amines in real-time, providing a simpler and faster approach compared to chromatographic methods (Vasconcelos et al., 2021). However, these techniques may lack the precision and sensitivity required for detecting low concentrations of amines in complex food matrices.

Enzyme-linked immunosorbent assays (ELISA) and other immunoassays have also been employed for BAs detection, utilising antibodies that specifically bind to target biogenic amines, allowing for their quantification. These methods are particularly advantageous for large-scale screening due to their high throughput and relatively simple protocol. However, they can sometimes suffer from cross-reactivity and may not provide the same level of specificity as chromatographic methods (Papageorgiou et al., 2018).

Spectrophotometric and colorimetric assays represent another cost-effective approach for BA detection. These methods involve the reaction of biogenic amines with specific reagents, resulting in a colour change that can be measured spectrophotometrically. While these methods are simple and inexpensive, they are generally less sensitive and may be prone to interference from other compounds present in food samples (Ruiz-Capillas & Herrero, 2019).

Various methods for detecting biogenic amines (BAs) in food offer different benefits. Chromatographic techniques like HPLC and GC provide high sensitivity and accuracy, though they involve complex preparation. Newer approaches, such as biosensors, enzymatic assays, and ELISA, offer faster, cost-effective alternatives but may sacrifice some precision. Simpler methods like spectrophotometric assays are affordable but less sensitive. The choice of method depends on the need for sensitivity, speed, and cost-effectiveness in different food safety applications.

5. THE MICROBIAL DIVERSITY IN ASIAN FERMENTED SHRIMP-BASED PRODUCTS

Fermented shrimp-based products, like shrimp pastes, are made through natural fermentation without the addition of specialised microbes. Instead, numerous microorganisms from the raw ingredients and the surrounding environment support the fermentation procedure. However, microbial growth can be controlled by acclimating environmental circumstances such as temperature, oxygen levels, pH, and salt concentration. In these fermented shrimp pastes, where salt fermentation predominates, most microbial populations consist of halophiles or halotolerant species, which persist in saline environments. Culture-dependent methods have typically been used to explore the microorganisms involved in the fermentation duration of shrimp species. For example, Bacillus species have been found as the prevalent starting genus in the fermentation of shrimp pastes throughout Asia, as shown in Table 5.

Bacillus species are acknowledged for their ability to produce extracellular enzymes, particularly proteases (Contesini et al., 2018), which significantly contribute to protein degradation during shrimp paste fermentation (Daroonpunt et al., 2016). The proteolytic activity of these enzymes hydrolyses proteins into peptides and free amino acids (Indriani et al., 2024), thereby intensifying umami taste and enhancing flavour complexity through the release of bioactive metabolites (Deng et al., 2022). Importantly, halophilic strains of *Bacillus* are capable of thriving in high-salt environments (Yao et al., 2023), well-adapted to the conditions typically found in traditional shrimp paste fermentation. This salt tolerance allows Bacillus to dominate the fermentation ecosystem, where their enzymatic activity plays a central role in shaping the sensory qualities of the final product (Indriani et al., 2024).

Lactobacillus species are primarily associated with lactic acid fermentation (Ilyanie et al., 2024), where their primary role is the production of lactic acid, which lowers the pH and inhibits the growth of spoilage and pathogenic microorganisms, thereby improving food safety (Herlina & Setiarto, 2024). In addition to acidification, certain *Lactobacillus* strains exhibit proteolytic activity, releasing peptides and amino acids that contribute to flavor enhancement (Herlina & Setiarto, 2024; Pongsetkul et al., 2022). The acidic environment created by lactic acid further influences the sensory profile of fermented shrimp paste by imparting tanginess, while simultaneously acting as a natural preservative.

Vibrio species, native to marine environments, are commonly detected during the fermentation of seafood products, including shrimp paste (Helmi et al., 2022). The presence of *Vibrio* strains is closely linked to flavour diversification but must be monitored due to their potential pathogenicity (Herlina & Setiarto, 2024). However, in controlled fermentations, their enzymatic contributions significantly shape the sensory qualities of the final product. The collective metabolic activities of these diverse microbial communities, including those that are salt-tolerant, such as *Virgibacillus halodenitrificans* ST-1, significantly influence the complex array of volatile and non-volatile compounds that define the characteristic aroma and taste of fermented shrimp paste (Liu et al., 2020).

However, microbial diversity changes significantly depending on salt concentration (Lee et al., 2014). Several factors, such as geographic origin, raw material composition, processing techniques, and environmental conditions, influence the composition and dynamics of microbial populations in fermented shrimp pastes, leading to variations in the final product's characteristics, particularly in terms of

Table 5: Microbiota composition in traditional Asian fermented shrimp-based products

Country	Product name	Species	Microorganisms	References
Malaysia	Belacan (shrimp paste)	*Acetes* spp.	*Staphylococcus, Tetragenococcus, Bacillus, Pediococcus, Lactobacillus, Micrococcus, Sarcina, Clostridium, Brevibacterium, Flavobacterium, Bacillus cereus, Staphylococcus aureus,* and *Corynebacterium*	(Chuon et al., 2014) (Huda, 2012)
Thailand	Kapi (shrimp paste)	*Acetes vulgaris*	*Lentibacillus, Salinococcus, Salimicrobium, Alkalibacterium, Staphylococcus, Jeotgalicoccus, psychrophilus,* and *Bacillus*	(Phewpan et al., 2020)
Indonesia	Terasi (shrimp paste)	*Acetes* spp.	*Tetragenococcus halophilus, Tetragenococcus muriaticus,* and *Bacillus cereus*	(Kobayashi et al., 2003)
			Tetragenococcus, Aloicoccus, Atopostipes, Alkalibacillus, and *Alkalibacterium*	(Helmi et al., 2022)
			Staphylococcus, Bacillus, and *Proteus*	(Huda, 2012)
Myanmar	Ngapi/ Hmyin (shrimp paste)	*Acetes* spp.	*Aeromonas liquefaciens, Alcaligenes faecalis, Bacillus alvel, Bacillus badius, Bacillus brevis, Bacillus cereus, Bacillus circulans, Bacillus polymyxa, Bacillus firmus, Bacillus laterosporus, Bacillus lentus, Bacillus macerans, Bacillus pantothenticus, Bacillus stearothermophilus, Bacillus subtilis, Corynebacterium hoffmanni, Kurthia sp., Lactobacillus, Streptobacterium, Pseudomonas fluorescens, Serratia marcescens,* and *Staphylococcus epidermidis*	(Kobayashi et al., 2003; Steinkraus, 2004; Pamungkaningtyas, 2023)
Korea	Saeuojeot (pickled shrimp)	*Acetes* spp.	*Vibrio, Photobacterium, Psychrobacter, Pseudoalteromonas, Enterovibrio, Salinovibrio, Staphylococcus, Halomonas, Salimicrobium,* and *Halanaerobium*	(Lee et al., 2014)
			Pseudoalteromonas, Staphylococcus, Salimicrobium, and *Alkalibacillus*	(Jung et al., 2013)
			Staphylococcus equorum, Halanaerobium saccharolyticum, Salimicrobium luteum, and *Halomonas jeotgali*	(Han et al., 2014)

aroma and taste (Bae et al., 2024). Further research is needed to understand the specific roles of this microbial diversity, as they may be responsible for producing metabolites that contribute to either desirable or undesirable flavours, aromas, or even safety concerns in shrimp products. Beyond identifying the microorganisms involved in fermentation, studying microbial diversity can also help predict the flavour profiles of fermented products and optimise fermenting processes (Phewpan et al., 2020).

6. CONCLUSION & FUTURE PERSPECTIVES

This article explores various aspects of fermented shrimp-based products, including their fermentation processes, amino acid composition, biogenic amine profiles, microbiological characteristics, associated risks, and future challenges. The analysis reveals a diverse microbial community and a high concentration of amino acids, particularly those that contribute to the umami flavour. The production of fermented shrimp products is primarily traditional, employing salting, drying, and natural fermentation. However, high salt content and the accumulation of undesirable compounds, such as biogenic amines, compromise their nutritional value and potential health benefits.

Advancements in innovative techniques are imperative to enhance the quality of fermented shrimp products, particularly the application of novel starter cultures and low-salt fermentation processes. Starter cultures can expedite fermentation, inhibit spoilage microorganisms, and reduce biogenic amine levels, as well as enhance developed strategies for controlling and mitigating harmful compounds to maximise health benefits. This study provides crucial insights for future research to improve the long-term food value of fermented shrimp products.

Fermentation remains one of the most effective methods for preserving shrimp, a critical food resource that contributes significantly to livelihoods and reduces post-harvest losses. However, challenges in the shrimp fermentation industry necessitate innovative approaches to overcome the limitations posed by traditional, empirically developed methods—many of which originate in Asian countries. While valuable, these methods often lack standardisation and scientific rigour, which affects product variability, quality, and food safety.

A primary challenge is detecting biogenic amines, which can accumulate in fermented shrimp-based products and pose significant health risks, including foodborne toxicity. Current research focuses on improving detection technologies, such as polymerase chain reaction (PCR)-based assays and next-generation sequencing. These provide heightened sensitivity for identifying pathogenic bacteria or amine-producing strains. In addition, microfluidic devices are emerging as promising tools for real-time, on-site detection of biogenic amines and other harmful compounds, offering faster and more reliable results than traditional methods (Kapoor et al., 2024).

Despite these advancements, widespread adoption faces several barriers, including the costly equipment, the requirement for technical expertise, and regulatory challenges. Integrating these cutting-edge technologies into food safety protocols will require substantial investment and collaboration across industry, academia, and regulatory bodies. Furthermore, global harmonisation of food safety standards is necessary to ensure consistency and effectiveness in reducing the risks associated with biogenic amine toxicity in shrimp-based fermentation.

Another challenge involves maintaining a balance between innovation and tradition. Fermented shrimp-based foods hold cultural significance, making it essential for production modification methods to respect these traditions while improving product safety and quality. Educating producers, particularly in small-scale, traditional settings, about the benefits of adopting new technologies will be crucial in overcoming resistance to change (Tamang et al., 2016).

In conclusion, the future of fermented shrimp-based products depends on the successful integration of advanced detection technologies, enhanced safety protocols, and multidisciplinary collaboration. Addressing these challenges will safeguard public health, preserve cultural traditions, and ensure the long-term sustainability of shrimp-based food systems.

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