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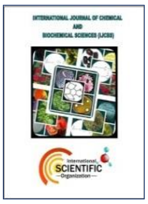

Organic Acids in the Fermentation and Production of Shrimp and Fish Paste: Formation, Functions, and Regulatory Concentration Standards

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Abstract

Organic acids are vital in the production of shrimp and fish pastes, influencing fermentation, preservation, flavor, and safety. These acids, primarily lactic, acetic, and propionic, are produced during fermentation facilitated by lactic acid bacteria. They enhance sensory qualities and extend shelf life by inhibiting spoilage and pathogenic microorganisms through pH reduction. However, their concentrations must comply with regulatory standards to ensure consumer safety and mitigate health risks. The integration of organic acids into seafood pastes not only supports preservation but also improves flavor complexity. Lactic acid provides tanginess, acetic acid adds a sharp, vinegar-like flavor, and propionic acid aids in microbial stability without altering taste. The combination of these acids enhances the texture, aroma, and overall sensory profile of the products. Adherence to permissible limits is critical, as excessive concentrations may pose metabolic risks. Regulatory bodies like the FDA and EFSA establish guidelines to ensure these acids are safely used within acceptable daily intake levels. Innovations in fermentation technology, including the use of starter cultures and controlled environments, offer opportunities for better management of organic acid production, improving product quality and consistency. Emerging non-thermal preservation methods, such as high-pressure processing, further ensure safety without compromising the natural characteristics of seafood pastes. Continued research into organic acid dynamics and alternative preservation techniques is essential to meet consumer demands for safe, high-quality, and naturally fermented seafood products, while maintaining compliance with global food safety standards.

Keywords: Organic acids; Fermentation; Preservation; Safety

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1. Introduction

Shrimp and fish pastes are some of the commonly used ingredients in various cuisines, especially in Southeast Asia, where their distinct flavors and textures and possible enhancements to different dishes qualify them as valuable ingredients [1-3]. These pastes were originally made by fermentation which has not only helped to create their original taste and aroma but also helps to keep them in good condition [4-7]. The fermentation process helps to transform the materials by allowing certain bacteria to digest some compounds and proteins contained in the fish products making the final product multi-flavored, while at the same time creating an environment for protein spoilage leading to preservation without chemicals [6-9]. This transformation is significantly aided by organic acids [3-9]. Lactic acid bacteria and other microorganisms synthesize organic acids such as lactic, acetic, and propionic acids during the fermentation process which lowers the pH of the product and creates unfavorable conditions for spoilage bacteria [10-12]. These acids support shrimp and fish paste's preservation and microbial stability as well as enhance their characteristic sourness, tangness and flavor complexity [13-15]. Different acids impact the sensory attributes of the product differently with regards to taste, aroma, or even texture of the product and this is usually dependent upon the kind and concentration of acid formed [6-16-18]. For this review, the organic acids produced during the fermentation and manufacture of shrimp and fish pastes will be described, and, the role they play in modification of flavor, texture and increasing the shelf life of the products will also be addressed. As mentioned above, this review also deals with the concentration limits of organic acid in these products as different parts of the world will apply different limits for the safety of the consumers. In consideration of the above objectives, this review presents the formation, function and legal dimensions of organic acids in production of shrimp and fish pastes, along with guarantees of quality and safety according to international approaches.

2. Organic Acids in Fermentation

Fermentation is a particular method utilized in preparing shrimp and fish pastes where raw seafood is biochemically changed into a tasty, shelf-stable product through natural processes [10-19-20]. The flow diagram of fermentation process for shrimp and fish paste can be seen in Figure 1. The natural fermentation of such seafood products is accomplished through indigenous or augmented microorganisms such as lactic acid bacteria that utilize starches and proteins contained in seafood [9-11]. Fermented food products also contain organic acids as a result of microbial synthesis, and these acids contribute to the flavor, preservation and safety of food product. The last few decades of marine bio resources processing technology development have expanded the possibilities of fermentation, which was traditionally used for preservation and flavoring of seafood pastes [9-21]. There is a natural accumulation of organic acids, namely lactic, acetic and propionic acids, during fermentation that are critical for the stability and quality of product [5-10-22]. Due to formation of such acids, paste pH reduced; thus, many spoilage and pathogenic microorganisms are inhibited. This acidic condition serves as an effective preservative wherein seafood pastes do not require refrigeration and are shelf-stable for prolonged [23-24].

Moreover, each organic acid also provides unique sensory attributes to the product. For instance, due to the presence of lactic acid, the resulting flavor is sour and tangy, adding depth to the product while acetic acid adds a more pungent sourness in addition to a vinegar flavor and provides additional antibacterial effects [25]. Although in much lower concentrations, propionic acid is also appreciated due to its excellent suppression effects towards certain bacteria and molds which further promote the storage stability of the seafood paste [22-26]. These organic acids are useful not just for the purposes of preservation, but also in improving flavor, aroma, and texture [4-10-27-28]. When combination of these acids exists in correct ratios, the rich and intricate flavors of shrimp and fish pastes are brought to life. These organic acids help explain behavior of volatile acids in organic substances that synthesized. As such, if one ignores their synthesis and other processes, one's way of producing and marketing should suffer through unnecessary losses of quality and safety standards. Producers can also ensure their products remain within permissible acid levels set by authorities.

3. Organic Acid Classes Used in Production of Shrimp and Fish Paste

When preparing shrimp or fish paste, organic acids can be either produced via the processes of fermentation, or, some forms can be injected in the product to increase shelf lifespan or taste [29]. Each acid has a specific purpose, particularly the enhancement of the paste's preservation properties, as well as the stability of the germs in the product and the taste of the product. The most common acids in the production of shrimp and fish paste include lactic acid, propionic acid, and acetic acid, with citric and malic acid being used less frequently (see Table 1). These acids are therefore evaluated in detail with respect to their importance in enhancing the overall stability of the product [29-31]. In sea fermentation, lactic acid is one of the main organic acids produced during the process. This acid is created by lactic acid bacteria that utilize the sugars and carbohydrates in the raw materials, leading to a decrease in the pH of the paste [32]. Through the production of lactic acid, which lowers the paste's pH, most pathogenic and spoilage microorganisms are inhibited from growing, naturally enhancing the product's shelf life [33]. Aside from boosting preservation properties, lactic acid adds a sour dimension to the paste, which increases its complexity and gives a nice depth to its tanginess [34].

Due to its antibacterial properties and its ability to improve texture, lactic acid is essential in the making of stable seafood paste [31]. Acetic acid is another widely used and important organic acid produced during fermentation. Characterized by its pungent, vinegar-like odor, acetic acid is extensively used to both preserve and add flavor to food. It serves as a powerful antifungal and antibacterial agent that targets a wide variety of bacteria and fungi, potentially reducing spoilage risks [34]. Due to its ability to reduce pH and high solubility, acetic acid is valuable in manufacturing of seafood paste, among others [40]. A combination of its sharp and unique flavor aids in enhancing umami elements in shrimp- and fish-paste flavors, which is achieved through use of acetic acid [41] Furthermore, additives that can inhibit spoilage bacteria effectively preserve the integrity of final products. Propionic acid, on the other hand, is present in smaller quantities but is highly valued in the production of shrimp and fish paste due to its strong antibacterial properties [31]. Propionic acid also combats molds and some bacteria, adding further protection to the paste during storage. Hence, propionic acid is considered a crucial component when producing seafood pastes designed for long shelf life, due to its ability to withstand harsh conditions.

Low but sufficient concentrations of propionic acid and other fractured compounds are reliable sources for fermented seafood stability. Even though propionic acid has virtually no impact on flavor, product safety heavily relies on its antibacterial properties [28-42]. During shrimp and fish paste production, acids like citric and malic are some of the less commonly found organic acids in the products. In fish paste, citric acid is seldom produced but often added as a pH stabilizer and antioxidant to maintain the color and freshness of seafood paste while also adding a tangy taste to the mix. Citric acid, therefore, can be particularly useful in fine-tuning fermentation conditions [34]. Malic acid, on the other hand, is commonly used to add a subtle fruity tartness, which complements the seafood flavor without overpowering it. These acids, though used in smaller amounts, enhance sensory properties of product, and in conjunction with primary acids such as lactic and acetic acid, help inhibit microbial growth [40]. Distinct taste, texture, & preservation of shrimp and fish paste owe much to these organic acids, which support fermentation process. These combined effects enable production of a fermented product with reasonable storage longevity and consumer appeal, all while ensuring safety standards are met. It is beneficial for producers to understand role of these acids in fermentation control and allowable levels of organic acids in seafood products [41].

4. Functions of Organic Acids in Fermented Shrimp and Fish Paste

Organic acids contribute to the safety, quality, and organoleptic properties of fermented shrimp and fish paste. These acids help to reduce pH levels, inhibit microbial growth, and even alter sensory properties; therefore, they serve not only structural purposes but also function as preservatives and flavor enhancers [43] . Organic acids, such as lactic and acetic acids, play essential roles in inhibiting spoilage microorganisms and pathogenic bacteria, which increases the shelf life and safety of the products [25]. These acids also enhance the sensory profile of the paste by contributing sour and tangy flavors that improve complexity and acceptance by consumers [23]. An explanation of these organic acids' contributions towards the enhancement of product safety, quality, as well as the factors that affect the acceptance of these products by users, is provided below. Diminished pH levels due to the presence of organic acids and their counteraction of spoilage microorganisms or pathogens significantly enhance the safety and quality of shrimp and fish paste.

Organic acids such as lactic, acetic, and propionic acids acidify the paste, creating conditions that are unfavorable for undesirable microorganisms [43]. The pH required by pathogens such as Listeria and Salmonella for survival is rendered unsustainable due to the production of these acids during fermentation [25]. Additionally, specific organic acids like acetic and propionic are known for their mold- and yeast-inhibiting properties, which contribute to the extended shelf life of the product [26]. Besides inhibiting microorganisms, organic acids also enhance the quality of seafood paste by stabilizing the product during storage. This function is essential in fermented foods, as it helps preserve the desired softness, color, and edible quality even over extended periods [23]. By combining pH reduction with antimicrobial action, organic acids allow manufacturers to produce safe and durable products without needing artificial preservatives. Shrimp and fish pastes contain sensory characteristics provided by each acid, including taste, smell, and texture, some of them:

Lactic Acid: Lactic acid is mild in sourness, adding a zesty flavor that complements the umami taste of shrimp and fish paste. Its mild acidity also contributes to texture strength common in seafood pastes. The effect on aroma is subtle, enhancing rather than overpowering seafood base [7-23].

Acetic Acid: Unlike other acids, acetic acid is not characterized by sharpness or flavor modification but rather by a pronounced vinegary tartness that enhances the overall flavor profile. In moderation, acetic acid's strong aroma complements savory qualities in seafood. While it is not typically structuring, a certain concentration can add aromatic complexity [43].

Propionic Acid: Propionic acid, though mild in taste, plays a crucial role in stabilizing the final product composition. Its low sensory impact makes it suitable for curing shrimp and fish paste without altering the flavor, while also contributing to a stable texture by preventing mold and yeast growth [26].

Other Acids (Citric and Malic): Citric acid adds a bright, citrusy flavor that enhances seafood taste harmony by adding sharpness to the acidic profile of the paste. Malic acid, which is less sour with a more fruity taste, provides a subtle tartness that complements natural flavor of shrimp and fish without masking it. These acids may also improve texture and have antioxidant properties that enhance paste's appearance [44]

5. Health Hazards of Naturally Occurring Organic Acids

The organic acids naturally present in fermented shrimp and fish paste contribute to improved preservation and flavor. However, their consumption, particularly in higher concentrations, can have metabolic implications (see Table 2). It is important to define permissible intake levels for these acids to ensure consumer safety and maximize their benefits without causing harm [25-45]. Lactic, acetic, and propionic acids are naturally produced in the body during metabolic processes. Lactic acid, found in fermented seafood, is generated through anaerobic respiration and is metabolized by the liver. When consumed in moderate amounts, it is generally safe and may even support muscle repair [23]. Similarly, acetic acid, found in vinegar, is converted into acetate, which supports the Krebs cycle and energy production. It has also been shown to positively influence blood sugar and lipid metabolism [46]. Propionic acid, although present in smaller amounts in seafood pastes, is also metabolized efficiently. Some studies suggest that excessive consumption of propionic acid could interfere with glucose metabolism and insulin response [26]. However, when consumed in moderate quantities, it generally does not pose significant health risks.

Research has also shown that propionic acid plays a role in inhibiting pathogenic bacteria in the gut, thus contributing to gut health [46]. The U.S. Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA) have established Acceptable Daily Intake (ADI) values for many commonly used organic acids. These values, based on toxicological studies, serve as safe consumption limits to protect public health. Regulatory bodies ensure that the intake of organic acids remains within safe boundaries, reducing the risk of adverse effects [25-47] Studies have also highlighted the safety of organic acids in food products when consumed within these established ADI limits [47-48]. Moderate consumption of organic acids from fermented foods, when kept within safe ADI limits, can offer health benefits such as supporting digestion and metabolism. However, excessive intake may cause gastrointestinal discomfort, especially in individuals not accustomed to acidic foods or those with sensitivities [23]. Understanding the health benefits and potential risks of organic acids is crucial for both producers and consumers to ensure the safe and effective use of these natural preservatives [48-49].

6. Organic Acids Exposure Legal Limits and Regulations

The use and concentration of organic acids in fermented seafood products such as shrimp and fish paste are subject to stringent food safety regulations to ensure consumer health (see Table 3). Regulatory bodies, including the U.S. Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA), play significant roles in setting these standards [50]. These regulations are formulated to mitigate potential risks associated with excessive exposure to organic acids while preserving the beneficial attributes of the fermented products [51]. Organic acids can be produced through fermentation or added directly to products [29]. Naturally occurring organic acids, like lactic, acetic, citric, and formic acids, are commonly found in fermented seafood, where they help enhance flavor, preserve the product, and improve safety by inhibiting harmful microorganisms [52]. In traditional fermentation, propionic acid levels can reach up to 4,200 ppm or 0.42 %, but this varies based on packaging materials of shrimp paste [53]. While these acids may form naturally during fermentation, food safety regulations worldwide govern their use to ensure concentrations remain safe and non-toxic [54].

The FDA also enforces strict guidelines on acceptable acid levels to prevent health issues such as metabolic acidosis and gastrointestinal problems, especially when these acids are consumed in excess or by vulnerable groups. EFSA regulations mirror these safety considerations, focusing on maintaining equilibrium between traditional food practices and modern safety standards [51]. Each organic acid must comply with allowable daily intake (ADI) levels determined through toxicological data and exposure assessments. Specific concentration limits for organic acids in fish and shrimp paste are established to harmonize safety and quality. The FDA typically categorizes acceptable limits based on the type of acid and the food matrix involved [52]. For example, lactic acid concentrations are monitored to ensure they do not exceed levels that could pose risks to consumers, while acetic acid levels are controlled to prevent potential corrosive effects and taste alterations. The EFSA's safety evaluations reinforce these limits by incorporating comprehensive risk analyses that consider dietary habits and regional consumption patterns. The European Union (EU) mandates compliance with the ADIs set for each acid, with lactic acid generally permitted up to 3.5% and acetic acid up to 2.0% in fermented seafood [54]. These benchmarks are established through scientific reviews of both toxicology and long-term consumption studies [50].

7. Challenges of Organic Acid Management

The use of organic acids in dried shrimps and fish pastes presents several technical and commercial challenges during production and marketing. To effectively inhibit microbial growth and meet regulatory limits, precise control of organic acid concentrations is required, involving careful management of fermentation parameters and rigorous quality assessments [59]. Producers face numerous challenges in using organic acids for food preservation, such as the impact of non-biological factors and the potential need to compromise between product safety, integrity, and regulatory compliance [60]. During the fermentation process, various organic acids, including lactic acid, acetic acid, and propionic acid, are produced due to variability in microbial activity and the substrates used. The concentration of lactic acid, for example, depends on the composition of raw materials (e.g., sugars or proteins), the microorganisms involved, and fermentation duration. In traditional bilberry vinegar production, estimating and controlling acid generation is challenging because fermentation process relies on diverse, localized flora found naturally within plants and fruit, leading to inevitable variations in lactic acid production [61].

These fluctuations complicate the quality assurance efforts and present ongoing challenges for maintaining consistent the product potency. Additionally, monitoring acid levels within specific production batches is labor-intensive and requires skilled personnel and advanced equipment, which can be costly and difficult for smaller producers operating on narrow profit margins. This creates significant obstacles for implementing stringent monitoring systems. The equilibrium of protonation and dissociation in molecules, though advantageous in theory, is practical only if high standards are consistently maintained throughout the production process [59-60]. Environmental parameters, particularly temperature and pH, play a crucial role in the production and accumulation of organic acids during fermentation processes. Temperature affects microbial metabolism significantly; high temperatures can accelerate the growth of acid-producing bacteria, potentially leading to excessive production of organic acids, sometimes surpassing desirable levels [59]. Conversely, low temperatures may hinder acid production, extending fermentation duration and risking depletion of beneficial microorganisms [62].

Similarly, pH concentration affects both the types and amounts of organic acids produced. Lower pH levels typically favor lactic acid production by lactic acid bacteria, but once it exceeds a certain threshold, other acids may begin to form. Managing these environmental parameters is challenging, as slight adjustments in temperature or pH can alter acid profile, potentially impacting product quality and safety. Precise control often required to optimize acid levels, but maintaining these conditions consistently can be difficult, especially in large-scale or traditional production settings [61]. The challenge of balancing product quality and safety with regulatory limits for organic acid concentrations remains substantial. Regulatory agencies set upper limits on organic acid levels to protect consumer health, but these restrictions sometimes limit naturally occurring acids in fermentation, possibly affecting product's flavor and preservation qualities. Producers of items like shrimp and fish paste, where organic acids are intrinsic to taste and texture, face unique challenges in controlling acid levels that enhance flavor and preservation while remaining within legal boundaries [59-60]. Presence of organic acids in fermented foods is generally widespread, though consumer acceptance varies.

While some consumers appreciate the sour notes of organic acids, associating them with quality and freshness, others might find high acid concentrations unappealing, associating them with spoilage. In certain regions, enthusiasm for organic acids—especially when perceived as naturally occurring through traditional fermentation—can even contribute to a positive reception [59]. For producers, managing organic acid levels is essential to avoid an overpowering acidic flavor that might reduce product attractiveness. Educating consumers about organic acids as beneficial components of fermentation, aiding in preservation and safety, could also improve acceptance. Nonetheless, balancing traditional flavors with market appeal is complex, especially for companies operating across different cultural landscapes [60]. In fermented shrimp and fish paste production, managing organic acids presents numerous challenges, from environmental and regulatory compliance to meeting consumer expectations. Addressing these requires careful control of fermentation, attention to product quality, and consumer education on the safety and traditional authenticity of these products [61].

8. Emerging Trends and Further Directions

Increasing demand for safe, high-quality fermented shrimp and fish paste spurred efforts to improve fermentation processes and organic acid management. Innovations in these areas could enhance product safety, quality, and consumer acceptance. Future research should focus on refining organic acid control, exploring alternative preservation methods, and optimizing the fermentation process to ensure high-quality seafood paste production [59-60]. Recent advances in fermentation technology offer new ways to control organic acid levels in seafood pastes. One promising approach is use of starter cultures designed to produce specific organic acids in controlled quantities. By selecting strains with desirable acid-producing properties, producers can better manage lactic, acetic, and other acids, improving flavor consistency and microbial safety [61]. Controlled-environment fermentation, where parameters like temperature, pH, and oxygen carefully monitored, is another approach to managing organic acid levels. This method ensures optimal acid production while preventing excessive acidification that could affect product quality. Advances in real-time sensors and automated monitoring technologies support large-scale production and consistent quality control [59-60]. While organic acids are effective preservatives, their use can be limited by sensory changes and regulatory constraints. There is growing interest in alternative preservation methods, including natural antimicrobials such as essential oils, plant extracts, and bacteriocins. These methods inhibit spoilage organisms while maintaining the sensory qualities of seafood paste. For example, using amino acids from herbal sources like rosemary and thyme has shown promise in enhancing both antimicrobial activity and flavor [59]. Innovative preservation technologies, such as high-pressure processing (HPP) and pulsed electric fields (PEF), offer promising alternatives to traditional methods. These non-thermal techniques effectively inactivate microbes in seafood pastes without relying on chemical preservatives, thereby preserving the product's quality and extending shelf life. These methods hold potential for improving food safety while maintaining the natural characteristics of the product [59-62].

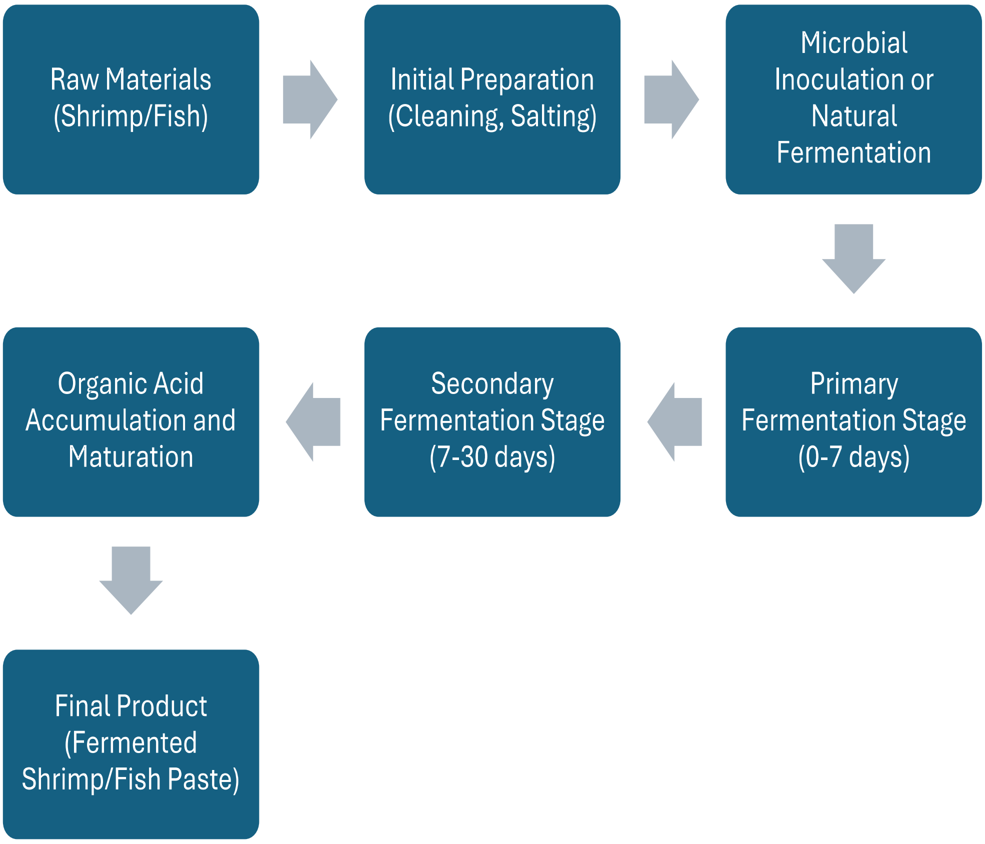

Figure 1: Flow Diagram of Fermentation Process for Shrimp and Fish Paste

Table 1: Common Organic Acids in Shrimp and Fish Paste with Their Functions

Organic Acid	Function	Sensory Impact	References
Lactic Acid	Preservation, pH reduction, texture enhancement	Mild sourness, tangy flavor	[29-31]
Acetic Acid	Antimicrobial, preservation, flavor enhancement	Pungent sourness, vinegar aroma	[35-36]
Propionic Acid	Antimicrobial, mold inhibition	Minimal taste impact	[28-31-37]
Citric Acid	pH stabilizer, antioxidant	Bright tangy flavor	[38]
Malic Acid	Flavor enhancement, subtle tartness	Fruity, delicate sourness	[39]

Table 2: Health Implications and ADI of Common Organic Acids

Organic Acid	Acceptable Daily Intake (ADI)	Health Implications	References
Lactic Acid	Generally recognized as safe (GRAS)	Metabolized by the liver; beneficial for muscle energy	[10]
Acetic Acid	Higher ADI due to common dietary use	Supports blood sugar control and metabolic health	[38-39]
Propionic Acid	Moderate ADI, safe in typical food use	May influence glucose metabolism if consumed excessively	[28-31-37]
Citric Acid	Considered safe within normal dietary use	Antioxidant properties; may cause mild irritation in excess	[38-39]
Malic Acid	Safe at typical levels in foods	Provides mild acidity; minimal health impact	[39]

Table 3: Comparative Analysis of Legal Concentration Limits

Region/Country	Regulatory Body	Lactic Acid Limit (%)	Acetic Acid Limit (%)	Propionic Acid Limit (%)	References
USA	FDA	Up to 3.5%	Up to 2.0%	Up to 0.5%	[10]
European Union	EFSA	Up to 3.5%	Up to 2.0%	Up to 0.5%	[35-55]
Japan	Ministry of Health, Labour, and Welfare	Up to 4.0%	Up to 2.5%	Up to 0.5%	[56]
Southeast Asia	Regional Food Safety Authorities	Up to 4.5%	Up to 3.0%	Up to 0.6%	[3-57-58]

9. Conclusions

As the demand for safe, high-quality fermented seafood products continues to grow, future research will play a critical role in overcoming current challenges. Research should focus on improving organic acid control, exploring novel preservation techniques, and optimizing fermentation processes to ensure the sustainability and quality of fermented seafood. By incorporating both traditional and innovative approaches, the industry can meet consumer needs while enhancing product safety and sensory appeal [59-62].

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